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Energy Analysis Tools

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Guidelines for Evaluating Energy Analysis Software

by
Linda Lawrie
William Bahnfleth

Design criteria documents used by Army designers are given little guidance either on modeling buildings of energy analysis or on using computer programs to perform the analysis. This report describes methods designers can use to evaluate energy related software used for whole building energy analysis and proves an Energy Analysis Calculation Tool Worksheet to use during evaluation.

The suitability of an energy analysis program depends to a large extent on the intended use. Rather than using a separate program for each application, it may be better to learn a very detailed program that will be suitable for all applications. Agreement between programs during evaluation does not guarantee agreement with real data. The program's successful solution of a simple problem may not be a good indicator of its ability to give similar accuracy for a complex problem.

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The suitability of an energy analysis program depends to a large extent on the intended use. Rather than using a separate program for each application, it may be better to learn a very detailed program that will be suitable for all applications. Agreement between programs during evaluation does not guarantee agreement with real data. The program's successful solution of a simple problem may not be a good indicator of its ability to give similar accuracy for a complex problem.

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FOREWORD

This work was performed for the Directorate of Military Programs, Headquarters, U.S. Army Corps of Engineers (HQUSACE), under Project 4A162781AT45, "Energy and Energy Conservation"; Technical Area A, "New Construction Energy Design"; Work Unit 017, "Energy Analysis Tools." Mr. Dwight Beranek, CEMP-ET, was the HQUSACE Technical Monitor.

Appreciation is expressed to Mr. Dwight Beranek, CEEC-EE, Mr. William Plunkett, CESAS-EN, and other Savannah District (CESAS) staff for initiating the Energy Analysis Calculation Tool Checklist and Energy Review Checklists contained in this report.

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The work was performed by the Energy Systems Division (ES), U.S. Army Construction Engineering Research Laboratory (USACERL). Dr. G. R. Williamson is the Chief of USACERL-ES. The Technical Editor was Gloria J. Wienke, USACERL Information Management Office.

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GUIDELINES FOR EVALUATING ENERGY ANALYSIS SOFTWARE

1 INTRODUCTION

Background

Several design criteria documents[1] used by U.S. Army Corps of Engineers (USACE) designers require that an energy analysis of buildings be performed during the design process. However, little guidance is given on proper procedures either for modeling buildings for energy analysis or for using computer programs to perform the analysis. Although designers are currently accomplishing the tasks as set forth in the criteria, specific guidance for long term implementation of energy conservation during the design process is needed.

The Department of Energy (DOE) has published an interim federal energy conservation regulation[2] for the design of new commercial buildings that is mandatory for Federal agencies. This regulation has stringent rules and requirements regarding energy analysis methodologies and programs.

Department of Defense (DOD) criteria have recently emphasized industry standards as reference documentation for many procedures. For example, Technical Manual (TM) 5-810-1[3] uses American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) practices to determine sizes for heating and cooling equipment. The Illuminating Engineering Society (IES) practices and procedures are used to determine artificial lighting requirements.[4] However, these standards focus on techniques suitable for manual calculations. Guidelines for selecting the automated tools needed for complex problems, such as whole building energy analysis, are lacking.

Building energy consumption analysis is a complex task that models building envelope structures, air handling systems, and equipment performance to produce estimates that represent the building's performance. The task is so complex that automated techniques are used routinely. In fact, both the Architectual and Engineering Instructions (AEI) and Air Force Regulation (AFR) 88-15 require that computerized energy analyses be performed for all medium to large building designs. The programs available on the market range from simple to complex and may not be generally applicable. Software evaluation is the responsibility of the designer, with considerations given to needs, cost, and other appropriate factors.

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[1]Architectural and Engineering Instructions (AEI)--Design Criteria (Office of the Chief of Engineers [OCE], 13 March 1987); Air Force Regulation (AFR) 88-15, *Criteria and Standards for Air Force Construction*, Interim Draft (Headquarters, U.S. Air Force [HQUSAF], January 1986); Engineering Technical Letter (ETL) 87-4, *Energy Budget Figures (EBFs) for Facilities in the Military Construction Program* (Department of the Air Force, 13 March 1987).

[2]Interim Federal Regulation, Federal Register, January 30, 1989, 10 CFR Part 435.

[3]Technical Manual (TM) 5-810-1, *Mechanical Design: Heating, Ventilating, and Air Conditioning* (Headquarters, Department of the Army [HQDA], August 1983).

[4]*IES Lighting Handbook: Reference Volume* (Illuminating Engineering Society of North America, 1981).

Objective

This report provides guidelines that designers can use to evaluate building energy analysis software to be used during the design process.

Approach

The energy analysis experience of about 50 USACE designers (obtained through informal discussions at group meetings on other subjects) was used as a basis for formulating the methodology. Several previous software evaluations conducted by USACERL and others were used as source documents and were summarized for inclusion in this report (Appendix A). During presentation of this material to several classes in the PROSPECT course "Energy Conservative Design of New Buildings," designers commented on how they would use this guidance.

Mode of Technology Transfer

It is recommended that this document and the Energy Analysis Tool Checklist be referenced in an Engineering Improvements Recommendation System (EIRS) Bulletin. It is suggested that material in this document and the referenced documents form the basis of a Technical Manual or other appropriate document that describes performing energy analysis of buildings.

2 ENERGY ANALYSIS OF BUILDINGS

Definition of Energy Analysis

Energy Analysis (EA) is the process of estimating energy requirements and fuel consumption of heating, ventilating, and air conditioning (HVAC), electrical, and other consuming systems for either short or long terms of operation. Three common elements associated with building energy analysis are the calculation of: (1) space load, (2) secondary equipment load, and (3) primary equipment energy requirements. Here, secondary refers to the equipment that distributes the heating, cooling, or ventilating medium to the conditioned spaces, while primary refers to the central plant equipment that converts fuel or electric energy to the heating or cooling effect.[5]

This concept contrasts with the equipment sizing calculations for the heating/cooling load requirements of a conditioned space. The approach to equipment sizing calculations centers around a 'worst case' scenario that represents the peak conditions that might be expected during the heating or cooling seasons. Both EA and sizing calculations have been adapted to automated techniques.

In addition to requiring computerized energy analyses, design criteria also require compliance with "building energy budgets/targets."* One of the typical uses of computerized energy analyses is to calculate the building's annual design energy use for comparison to these budgets/targets.

Building Models

Although heating/cooling load determinations are performed on a room by room basis or for a block of rooms, energy consumption estimates must consider the entire building. Since academic training may teach load determination but not EA, typical approaches are to apply similar techniques to define building models for energy analysis. These approaches are not incorrect but may not use the designer's time nor the automated program efficiently. Thus, the energy analyst needs specific guidelines on modeling the building architecture and energy systems for calculating the energy consumption. Of course, modeling of energy systems (HVAC, electrical) is important as well.

The energy analyst must also consider occupancy effects (internal heat gains/losses from equipment, lighting schedules, and air circulation) in the building model. External effects such as shadowing from landscaping or other buildings may play a significant role in the energy use calculations. Caution must be used when energy analysis tools are used as "actual building consumption predictors." Actual building operations have many factors, such as occupants or imperfect mechanical systems, that cannot be easily modeled in computer programs. Computer programs will model correctly operating

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[5] *ASHRAE Handbook of Fundamentals* (American Society of Heating, Refrigerating and Air-Conditioning Engineers [ASHRAE], Inc., 1985), Chapter 28.

*Building energy budgets are defined by facility type and climatic region, in terms of energy use per square foot per year. Artificial building requirements (standard hours of operation, omission of process loads, etc) are applied to the basic building design of a facility to calculate the "energy budget." Predefined tables of energy targets are used to measure compliance.

conditions and will, at best, make assumptions about effects of deteriorating maintenance conditions (such as dirty air filters). Even if computer programs could simulate the actual conditions, the amount of user data collected and resulting building model definition would be enormous. However, these factors should not deter analysts from using these tools for "trend analysis" in actual building conditions. For example, using "as is" models for comparisons to retrofits (whether strutural or mechanical) or to more perfect operating conditions.

Although a building model can simulate building energy use under the given conditions and assumptions, energy analysis studies are not intended to predict the exact energy consumption. Often, studies will be performed on facilities with similar functions but different architecture. For these studies, the differences in the results are more important than the bottom line exact energy consumption.

DOD criteria specify a design energy target for a facility type. This target, an artificial parameter, is based on standardized models of buildings. The occupancy hours used to determine the target (and thus the lighting and temperature schedules) may bear no resemblance to the actual building functional requirements. Thus, two or more energy analysis runs must be used to gain the total picture for the building: one for target compliance and one for building consumption and equipment sizing.

Simplification of Building Models

Information from *Use of Simplified Input for BLAST Energy Analysis*[6] should be used as the basis for creating building energy analysis models. The guidelines presented in that report (Table 1) are generally applicable to defining building models.

Some programs do not allow more detail than listed in Table 1. Other programs may allow more building details than Table 1 shows, but may be simplified (which may reduce running costs) using Table 1 guidelines.

[6]D. Herron, et al., *Use of Simplified Input for BLAST Energy Analysis*, Technical Report E-185, ADA131261 (U.S. Army Construction Engineering Research Laboratory [USACERL], May 1983).

Table 1

Guidelines for Energy Analysis Models

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1. Multifloor buildings need not have each floor modeled as a separate zone. Instead, the building can be modeled as one or more tall zones equal in height to the total building height.

2. Individual rooms can be grouped into one large zone if their use patterns and internal loads are similar. Grouped rooms do not have to be physically adjacent.

3. Interior spaces must be separated from exterior spaces.

4. Interior partitions can be ignored as long as their internal mass is accounted for.

5. The actual location of walls, windows, and doors are not needed unless some parts of the building shade themselves

6. The actual shapes of walls, windows, and doors are immaterial as long as the area and orientation are accounted for.

7. North- and south-facing spaces may be combined if the solar gain is not appreciable (i.e., if the south-facing walls have only a small amount of glass).

8. The effects of slab-on-grade floors, crawlspaces, or basements must be accounted for.

3 SELECTING APPROPRIATE TOOLS

Description of Energy Analysis Programs

Although all energy analysis procedures and programs strive to calculate an annual energy consumption of the building model, the assumptions (algorithms) underlying the calculations have a significant impact on the results. These programs are highly dependent on the user input, and since they are modeling an entire building, they can accept a wide variety of inputs to describe the building.

Studies have shown that a single user working with two different programs will achieve more similar results than two people using two different programs or two people using the same program.[7] To effectively use these programs, it is necessary to understand some of the major assumptions underlying the calculations. After learning one program very well, the user can easily transfer to another program that uses the same assumptions. It is much more difficult to transfer to another program with differing assumptions.

The tool chosen to study the energy impacts of a building design should be used at the appropriate degree of complexity for the items studied. Many of the complex programs can adapt themselves to simpler inputs as well as the complex issues. If one program can serve several purposes, users will be better off learning that program well than trying to use a new program for each new building element to be studied.

The following descriptions of energy analysis programs will help designers, project managers on A/E contracts, and others select a program to fit the needs of a proposed design. Descriptions of some specific programs and techniques used in these programs is also presented.

True 8,760 Hour-by-Hour (HBH) Programs

These programs use hourly weather data (temperature, solar radiation, wind speed, barometric pressure, and cloudiness indicator) to calculate the whole building energy consumption on an hourly basis. This weather data is available from a variety of sources including the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Air Force Environmental Technical Applications Center (USAFETAC). HBH programs complete 8,760 separate calculations of building energy use for each year of simulation.

For example, BLAST (U.S. Army Corps of Engineers), DOE (Department of Energy), ESPII (Automated Procedures for Engineering Consultants), and the Energy Systems Analysis Series (Public Works of Canada) are HBH programs.

Strengths. These programs are the best to use when highly accurate simulation of dynamic heat transfer through the building envelope has a strong bearing on which design alternative will be selected. Therefore, designs that include active or passive solar heat, heat reclaim based on time of day loads, and shading features of buildings are modeled best with these programs.

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[7] T. Kusuda, "A Comparison of Energy Calculation Procedures," *ASHRAE Journal*, Vol 23, No. 8 (1981).

Limitations. By performing 8,760 separate heat balance calculations, these programs take more computer time for each "run" and have traditionally required that a mainframe or minicomputer be used. Because the power of personal computers and engineering desktop workstations is becoming sufficient to handle these programs, the traditional computer investment concern (the cost of equipment and computer time) is becoming less of a handicap. These programs can simulate the building in great detail, though they can often be used in simpler situations with equally accurate results.

Condensed Hour-by-Hour (CHBH) Programs

These programs perform hourly calculations for "typical" days throughout the year. The programs read weather data that has been reduced from 8,760-hour data into 3 or 4 typical days per month. The number of heat transfer calculations for an annual simulation is reduced from the 8,760 required in the HBH programs to approximately 864 (assuming 3 days per month). Annual consumption is extrapolated from the use calculated for the typical days. Input requirements may range from simple to complex building models. For example, Trane Air Conditioning Economics Computer Program (TRACE, the Trane Company) and Hourly Analysis Program (HAP, Carrier Corporation) are CHBH programs.

Strengths. These programs perform heat balance calculations based on actual weather conditions, though not to the accuracy of true HBH programs. They can be used dynamically to model HVAC systems, lighting, and other design features to compare relative performance. Since these programs perform fewer calculations, they use fewer computer resources per simulation.

Limitations. These programs do not satisfactorily model design features that heavily rely on the effects of dynamic heat transfer in the building mass (e.g., passive solar features). They may not be as accurate as HBH programs when modeling time-of-day energy strategies such as thermal storage.

Bin and Degree Day Programs

These programs use weather data that is usually published in tables divided into temperature "bins" or degree days. They do not use actual weather conditions to perform energy consumption calculations. Examples include EN4M (MC2 Engineering Software), SEA (or Simplified Energy Analysis by Ferreira and Kalasinsky Assoc.), ASEAM-2, (ACEC Research and Management Foundation), and SASEAP (or Sud Associates Simplified Energy Analysis Program by Sud Associates Computer Programmers).

Strengths. These programs require a minimum of input data and computer run time. Some of the techniques can even be performed as hand calculations. These programs are suited for modeling simple buildings and systems, the performance of which is not highly dependent on hourly weather changes. Storage buildings with simple HVAC systems and controls could be evaluated with these programs. These calculations can also provide a rough picture of a building at an early design stage.

Limitations. These programs cannot model satisfactorily the effects of solar heat transfer or effects of mass on a building's energy performance. They are not suitable for examining time dependent control strategies such as night setback, duty cycling, storage systems, and daylighting.

Energy Analysis Program Checklist

Table 2 is an example checklist that can be used by project managers or the design team to help select the proper calculational tool.

Other Guidance

In addition to the above categories, EA computer programs can be grouped by the kinds of design features for which they have computation algorithms. Careful substitution between the categories may be made. For example, if a CHBH program is substituted for an HBH program because the HBH program does not contain a certain system or building feature, the user must be very cautious in broadly applying the results. Only a user who is intimately familiar with the limitations and inaccuracies introduced by this substitution should attempt the replacement.

The user must also be aware that programs may have flaws ("bugs") or may be representing their performance inaccurately. It is up to the user to determine if the program is appropriate for the application.

Section 12 of the new interim federal regulation, which will be the compliance path selected for most DOD facilities, refers to the calculational tool used for the whole building compliance. This tool:

- Shall be capable of modeling more than one zone per building
- Shall account for dynamic heat transfer through the envelope
- Shall be capable of modeling solar and internal loads
- Shall model part load performance of equipment
- Shall model controls for lighting, HVAC systems, and other equipment including strategies such as night setback
- Shall be an hour-by-hour model (8,760 hourly calculations per year of simulation) or approximate it with similar results
- Shall be capable of calculating energy costs and utility rate structures, and shall be capable of discounting and escalating values, methods, and other factors as needed for the proposed design.

The new interim federal regulation prohibits use of a tool that is clearly incapable of performing the required compliance calculations. For example, some programs cannot model certain HVAC systems such as heat pumps. When the proposed design uses heat pumps as the heating and cooling equipment, these programs shall not be used to model the annual energy consumption or costs. When an ice storage system that relies on using offpeak electricity to achieve energy cost savings is under consideration, the user cannot rely on a program (or set of programs) that is incapable of accurately modeling time-of-day electrical rate schedules. On the other hand, if the proposed design is very simple, a less comprehensive tool may be used to demonstrate compliance.

No single computer program can calculate all the energy alternatives and cost and life cycle cost analyses mentioned in the new interim federal regulation. For example,

Table 2

Energy Analysis Calculation Tool Checklist

PURPOSE: To assist the designer and project manager in the selection of the energy analysis calculation tool suitable for the project being undertaken.

PROCEDURE: Review the items of consideration listed below. Check off all the items that are pertinent to the energy analysis to be undertaken. Note the type of energy analysis tool recommended to the right of each item. Select the tool(s) that best fits the requirements of the analysis. Some analyses may be so extensive that more than one type of tool should be used. Disregard items not applicable to the analysis in question.

KEY: HBH = True 8760 Hour by Hour Computer Program
CHBH = Condensed "Hour by Hour" Computer Program
BIN = ASHRAE BIN Analysis Computer Program
HAND = Hand calculations based on BIN or Degree Day methods

ITEM	RECOMMENDED TOOL(s) HAND	BIN	CHBH	HBH
1. The building is air conditioned and:				
A. < 8000 sq ft	XX	XX	XX	XX
B. > 8000 sq ft			XX	XX
2. The building is heated only and:				
A. < 20000 sq ft	XX	XX	XX	XX
B. > 20000 sq ft			XX	XX
3. The function of the facility is mainly:				
A. Storage or warehouse	XX	XX	XX	XX
B. General office/administrative		XX	XX	XX
C. Training classrooms		XX	XX	XX
D. Barracks/family housing		XX	XX	XX
E. Motor repair and other garage			XX	XX
F. Hangars			XX	XX
G. Hospital				XX
H. PX/Commissary			XX	XX
I. Manufacturing/other process			XX	XX
4. The building envelope(s) under consideration are:				
A. Standard, simple and homogeneous	XX	XX	XX	XX
B. Complex/multilayer			XX	XX
5. The thermal loads on the building are:				
A. Almost entirely weather dominated	XX	XX	XX	XX
B. Weather dominated/some internal loading		XX	XX	XX
C. Highly internal loaded			XX	XX
D. High percentage of process loads				XX

Table 2 (Cont'd)

ITEM	RECOMMENDED TOOL(s) HAND	BIN	CHBH	HBH
6. HVAC systems being considered are:				
A. Simple off the shelf (i.e. fin tube)		XX	XX	XX
B. More complex off the shelf (i.e. VAV)			XX	XX
C. Special energy conserving (i.e. Heat reclaim chillers)			XX	XX
D. Ice or water storage			XX	XX
E. Active solar				XX
7. The purpose of the energy analysis is mainly:				
A. Siting and orientation analysis	XX	XX	XX	XX
B. HVAC system selection		XX	XX	XX
C. Passive solar analysis				XX
D. Active solar analysis				XX
E. Electrical system selection			XX	XX
F. Daylighting analysis				XX
G. DOD Energy Target/Budget Calculation		XX	XX	XX
H. DOE Building Energy Cost method			XX	XX
I. DOE Annual Building Energy Target method			XX	XX
J. Glazing/Fenestration analysis				XX
8. The results of the energy analysis will be used for:				
A. Life cycle cost analysis (LCCA) with simple fuel pricing structure		XX	XX	XX
B. LCCA with complex electrical or other fuel pricing structure			XX	XX

the DOE 2.1C program will perform a comprehensive calculation for time-of-day electrical rate structures but will not calculate the life cycle cost (according to DOD specifications) of the design alternatives. In cases like this, the user must choose a group of programs to complete the compliance check. For example, the annual energy cost data from the DOE 2.1C simulation could be used as input to a life cycle cost program that meets DOD requirements. The combined results of the output from both programs would satisfy the DOD compliance requirements.

Building Loads and System Thermodynamics (BLAST)

The Building Loads Analysis and Systems Thermodynamics (BLAST) system (Figure 1) is a comprehensive set of computer programs to help designers determine the energy requirements of a facility design. The calculations are performed on an hour-by-hour basis for an entire year (8,760 hours) of weather conditions. Hourly weather data is available from a variety of sources, usually including dry and wet bulb temperatures, barometric pressure, wind speed, wind direction, solar radiation values, and cloudiness

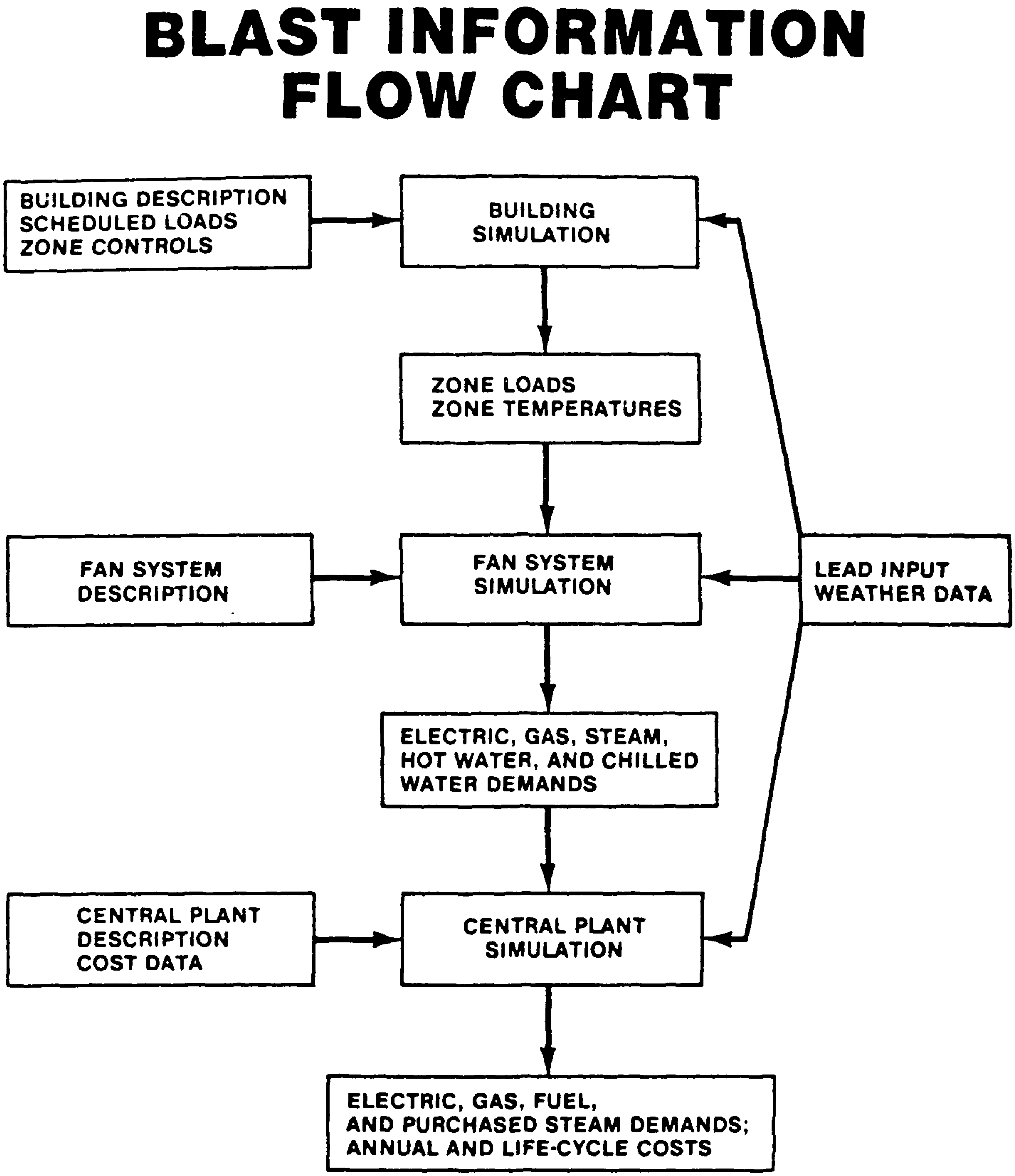

Figure 1. BLAST information flow chart.

indicators. BLAST uses these weather data elements in conjunction with the building envelope, HVAC system, and building equipment calculate the building's design annual energy use.

BLAST was developed at the U.S. Army Construction Engineering Research Laboratory (USACERL) and is supported by the Corps-contracted BLAST Support Office. BLAST is available in mainframe, minicomputer, and microcomputer versions. It is monitored by the Corps of Engineers' National Energy Team (CENET) and the BLAST User's Group to assure its effective use within the Corps. Although BLAST is a very complex and comprehensive program, it can be used simply through the BLAST Text Input Preprocessor (BTEXT). BTEXT is a menu-driven program that allows the designer to describe the building simply, and produces the standard BLAST inputs. BTEXT was also developed at USACERL, is supported by the BLAST Support Office, and is available in three computer versions.

BLAST uses a transfer function technique to calculate the heat transfer through the building envelope and within the building interior. Transfer function techniques are used to simulate the dynamics of heat flow through walls, roofs, and other envelope structures. BLAST also calculates radiation exchange between surfaces and convection between walls and room air. An energy balance is used to compute surface and room temperatures. Thermal mass of a material is accounted for within the transfer function technique.

The heat transfer calculation is particularly suitable for simulating the passive solar effects on the building. The solar gain on a massive wall may only gradually transfer through to the interior of the building. Likewise, after sunset, a massive building will gradually lose the heat stored in the walls and prediction of time at which heat transfer reaches equilibrium is easily accounted for by the transfer function technique. This technique can help the designer determine how a massive building will help the building energy use by shifting the peak load conditions (i.e., shifting a cooling peak from the hottest hour of the day to somewhat later). Quasi-steady analysis used in some simplified energy analysis methods does not allow for the time delay and spreading of heat loads resulting from the thermal mass.

The BLAST program performs the energy analysis of a building in three steps: (1) simulation of heating/cooling loads based on envelope and internal requirements, (2) simulation of the HVAC system that delivers conditioned air (including effects of outside air) to the various building parts, and (3) simulation of the equipment (including efficiencies) and determination of total energy demands of the building. This is the traditional energy analysis approach for simulating energy consumption in buildings.

The PROSPECT program offers two BLAST training courses: a basic BLAST training course (5 days) and an advanced BLAST course (3 days). Both courses offer hands-on instruction and lectures about energy analysis in buildings.

The Life Cycle Cost in Design (LCCID) program, a companion program to BLAST, performs the DOD life cycle cost calculations for DOD and the new interim federal regulation requirements. This program could be used with other energy analysis program results to perform the DOD life cycle cost analysis requirements.

Department of Energy (DOE)

Another HBH energy analysis program is the DOE program (Figure 2). DOE is supported through the Lawrence Berkeley Laboratory (LBL), Berkeley, CA, and has been used extensively in creating the tables and philosophy for the new interim federal regulation. The current version is DOE 2.1C. BLAST and DOE 2.1C have similar roots, but differ significantly in their approaches to simulating heat transfer through the building's construction.

DOE calculates loads assuming a constant temperature in the conditioned space. The thermal storage effect of the envelope components is simulated by applying weighting factors to internal and solar gains. Custom weighting factors may also be generated by the user for the building being analyzed. The effect of assuming a constant space temperature is corrected by a perturbation technique in the second stage of the program when the heating and cooling system is simulated. Because thermal mass effects can be modeled, DOE can accommodate passive solar studies of buildings.

There are two existing microcomputer versions of the DOE program: DOE 2.1B and DOE 2.1C. Neither microcomputer version is supported by DOE or by LBL.

"Hourly" Energy Analysis Programs

Several of the available energy analysis programs are called hour-by-hour simulations, but they do not simulate for 8,760 hours. These programs simulate the building for a certain number of "typical" 24-hour days. The building's annual energy consumption is then calculated by multiplying these typical day results to extrapolate the annual amount. The heat transfer calculation methods are similar to the BLAST and DOE programs.

Modified Bin Method Energy Analysis Programs

Modified bin method analysis is popular among microcomputer-based energy analysis programs. This method requires the weather data to be expressed in "temperature bins"--the number of hours in a certain temperature range (or bin). These bins may also include coincident wet bulb temperatures for each dry bulb temperature bin. In the modified bin method, average solar gain profiles, average equipment and lighting use profiles, and cooling load temperature difference (CLTD) values are used to characterize the time-dependent diversified loads of the building. CLTDs approximate the transient effects of the building mass. Time dependencies resulting from scheduling are averaged over a selected period. Loads from solar gains are established by determining a weighted-average solar load for a summer and a winter day, which then establishes a linear relationship of this solar load as a function of outdoor temperature. Once a total load profile is determined as a function of outdoor ambient temperature, the performance of the HVAC system is computed by calculating the heating and cooling coil loads. Annual energy consumption at the coils is determined using the bin-hour weather data. Finally, the annual plant energy consumption is calculated using boiler and chiller part-load performance models.

Another degree day approach that may be more applicable for DOD use is the variable base degree day method. This method is based on the balance point temperature (TB), defined as the average outdoor temperature at which the building requires neither

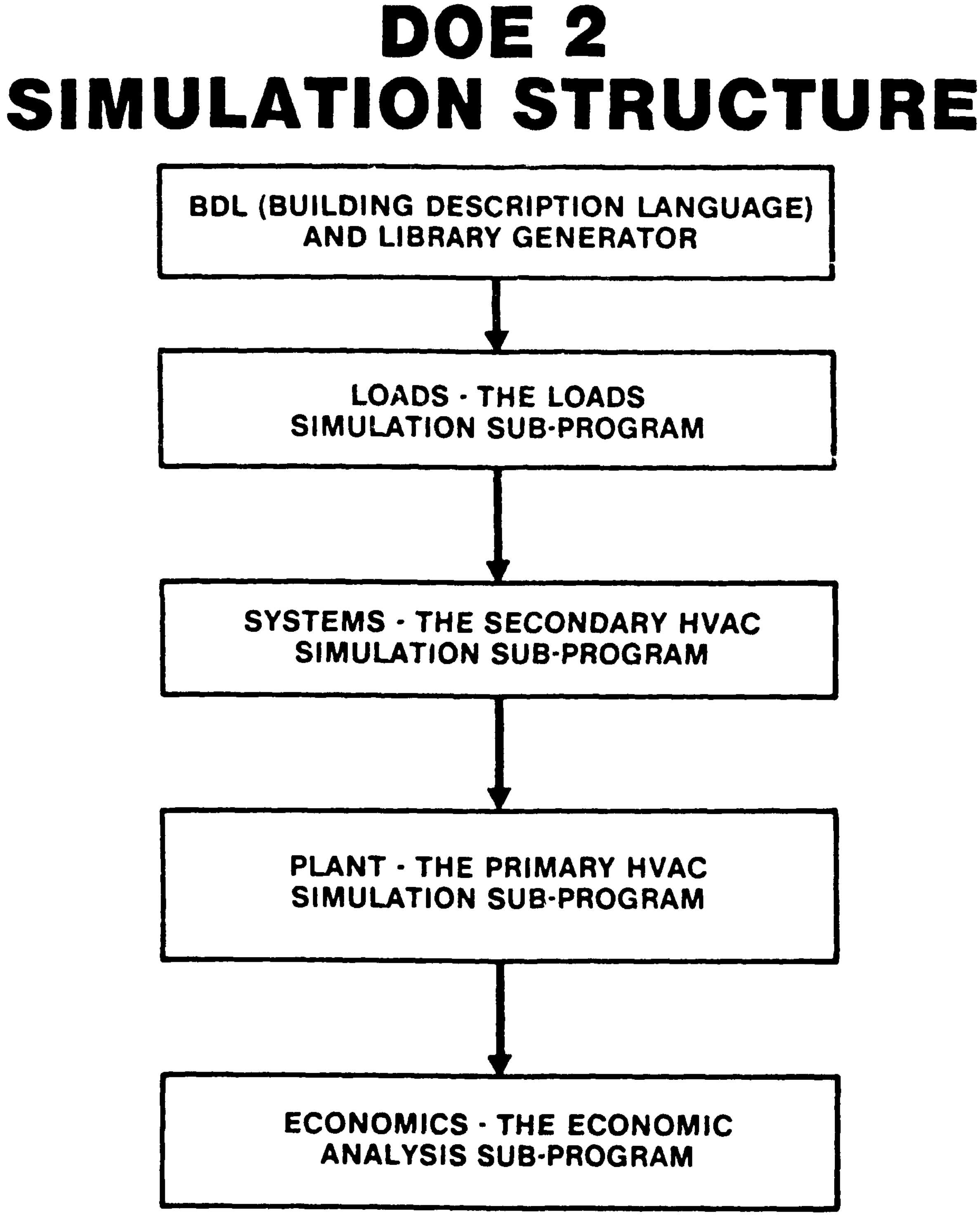

Figure 2. DOE 2 simulation structure.

heating nor cooling. Once a balance point temperature is determined for a building, the energy consumption is simply calculated as:

$$E = \frac{24 \times BLC \times DD@TB}{k} \qquad \text{[Eq 1]}$$

where:
E = Energy consumption for heating
BLC = Building Loss Coefficient
DD@TB = the degree days figured at TB
k = correction factor including effects of rated full load efficiency, part load performance, oversizing, and energy conservation devices.

There is considerable flexibility in the variable base degree day concept since E can be calculated for periods as short as a few days and as long as a season. (Total consumption would be figured as the sum of E.)

Types of Energy Analysis Studies

As noted earlier, several kinds of energy analysis studies may be useful during design. For example, studies can be performed to determine which mechanical system will have the correct size and functions, be energy efficient, and be cost effective for a particular building configuration. Studies of multiple building configurations (e.g., one story vs two story) meeting the functional requirements can also be performed. Other studies can focus on the architectural materials used in the building envelope.

Energy studies can also be useful in selecting building retrofit applications. Energy analysis programs can be used to simulate the building performance and the cost of several retrofit options before construction.

Energy analysis programs can also be used to diagnose building problems. Since some programs can predict temperatures for unheated/uncooled spaces, comfort studies can be done using actual weather data and building configuration. Significant dollar savings can result from conducting simple simulated building studies rather than using the actual facility as the experimental base.

DOD use of energy analysis programs and hand calculations in the past has typically been to calculate a design energy budget, or design energy target number. This has left the real power of these tools untapped because good energy analysis tools, properly input and interpreted, can reveal a wealth of information for improving the quality of a design. Other uses for energy analysis include:

- Determining the overall efficiency (with part load performance) of HVAC equipment

- Comparing the energy consumption of alternative siting, lighting, wall sections, windows, HVAC equipment and systems, energy sources, and occupancy patterns

- Doublechecking the equipment sizing or showing the effect of oversizing.

Reviewing Energy Analyses

Research was performed using the BLAST program and field users to understand the needs of energy analysis reviewers.[8] A special report was included in the BLAST program reflective of those needs (Appendix B). Though implemented in BLAST, similar formatted reports could be included with any energy analysis program. This type of report could streamline the USACE energy review process, making reviewers more productive.

When the BLAST computer program is used as the energy analysis tool, most of the review effort can be concentrated on this special Executive Summary Report, or BLAST Review Report. From this report, the reviewer may determine:

- If the proper version of the program has been used
- If the correct U-values have been modeled
- If the correct occupancy patterns have been modeled
- If the windows, HVAC system, and controls are correctly modeled
- The calculated energy consumption on an annual basis for all zones, mechanical systems, and equipment configurations
- If there are any "unmet loads" that affect the results (Unmet loads will be shown in output reports from the energy analysis programs. They could be caused by a variety of cases, such as a calculated heating requirement [to meet a space temperature] that was not supported by the heat capacity of a furnace. Other cases would include an air distribution system that delivers more cooling or heating than is required.)
- The design energy target (Btu/sq ft/yr) for the building
- If the analysis has been performed reliably, and what other BLAST reports may be needed for further information.

When reviewing the reports of other energy analysis programs, the first determination should be regarding the suitability of the program to perform the required analysis.

- What kind of program (e.g., HBH, bin, degree day) is needed for the study based on the complexity of the design and the types of options being studied?
- Is the program as good or better than the type required (Table 2)?
- Do the reports provide the data from which to judge how well the design complies with energy criteria (e.g., energy consumption by fuel source for use in life cycle cost analysis, Btu/sq ft/yr design energy consumption, verification of building model used, etc.)?

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[8] D. Leverenz, et al., *Use of the Building Loads Analysis and System Thermodynamics (BLAST) Computer Program to Review New Army Building Designs for Energy Efficiency*, Technical Report E-190, ADA134487 (USACERL, October 1983); J. Amber, D. Leverenz, and D. Herron, *Automated Building Design Review Using BLAST*, Technical Report E-85/03, ADA151707 (USACERL, January 1985).

When reviewing for compliance, the calculated annual energy use from the computer program should be compared to the proper DOD Design Energy Target table (these may differ depending on the military branch). The occupancy schedules used in the program should be the same as used in the Energy Target table. Since the targets do not include process loads, the output must be checked to ensure that process loads are not included in the calculations. These and other pointers are included in the checklist (Table 3).

Any discrepancies of calculated consumption greater than the target should be noted in the design analysis. Every attempt should be made to provide life cycle cost effective design improvements to reduce the annual energy use to the required target, without compromising the building function or occupant comfort. Reviewers, relying on experience and the criteria, should make specific comments to the designer regarding meeting the target and/or explaining the calculated energy use. Often, the energy target is exceeded because of problems using the calculational tool (computer program or hand calculations). The reviewer should attempt to find these sources of error and comment accordingly on the design. Problems may include:

- Incorrect occupancy and lighting schedules
- High unmet heating and/or cooling loads
- Inclusion of process loads
- Other building modeling problems.

Reviewing energy studies that compare actual building data to the analysis results must be done carefully, as noted in the discussion in Chapter 5 on benchmarking results. To this end, the output of the computer program should not be the only documentation reviewed. Assumptions made by the user should be carefully laid out so the reviewer can decide if these assumptions are warranted.

Table 3

Energy Review Checklist

	Item	Yes	No	Remarks
1.	Are Occupancy Schedules consistent with design?			
2.	Are HVAC Systems modeled correct for design?			
3.	Are HVAC and Lighting schedules correct?			
4.	Are U-Values consistent with design?			
5.	Is percent glazing correct for design?			
6.	Are there relatively large unmet loads for heating or cooling?			
7.	Are solar loads included?			
8.	Is size of building (sq ft) correct?			
9.	Are there "fatal errors" or other messages in report?			
10.	Is HVAC equipment sized per design?			
11.	Are energy sources consistent with design?			
12.	Does design energy use comply with design energy target?			
13.	Is location correct per design? Is weather data appropriate?			
14.	Are temperature schedules correct per design?			

4 SELECTING TOOLS FROM VENDOR DOCUMENTATION

Selecting computer software using only the vendor documentation or vendor sales information is a gamble. To some extent, industry standards for engineering applications often exist and computer programs must comply with those standards. Therefore, engineering software documentation typically references the appropriate standards. ASHRAE techniques and procedures[9] should be the primary reference for energy analysis.

After referencing the basis for the calculations, the user must evaluate whether the software will meet the price constraints, accuracy requirements, modeling, and general needs of the office. Often, vendors will offer demonstration versions of their software (particularly microcomputer based) so the user can try it.

An ideal documentation package will contain:

1. An introduction sufficient to tell the user whether the software will meet the needs

2. A description of the program's capabilities and limitations including theory overview

3. An unabridged data preparation and output interpretation guide

4. Appendixes or chapters that give a full discussion of theory and contain an abbreviated input preparation manual for the experienced user

5. Manuals that are profusely illustrated and complete without being tedious.

Regardless of how the software is selected, it is suggested that a rigorous evaluation be performed either before actual purchase or directly afterward. A good example of this kind of study was performed at USACERL.[10]

[9] ASHRAE Handbook of Fundamentals.

[10] W. Bahnfleth, D. Herron, and K. Ruby, *Evaluation of Building Design/Analysis Software for Microcomputers*, Technical Report E-88/01, ADA188134 (USACERL, November 1987).

5 SELECTING TOOLS WITH BENCHMARKS

Performance testing of programs may be done for many reasons. A few of the more common situations in which performance tests may be useful are:

1. Head-to-head comparisons of unfamiliar programs with familiar programs or with actual building consumption data

2. Comparison of old and revised program versions

3. Installation of a familiar program on new hardware

4. Change of user.

In each instance, the objectives of the test must be reflected in the design of benchmark cases. One of the more important principles of benchmark design for an individual user is that cases should correspond to the type of situations encountered in actual practice as much as is possible. Generic benchmarks are of limited use and far less important than those that the user compiles. Interpreting benchmark tests is as much art as science; it requires both intuition and technical skills. Agreement on small, simple models does not imply similar success with large complex models. Global agreement can mask large and opposing discrepancies in component loads. Experience with both actual building performance and simulation are invaluable aids to recognizing such problems and should be put to use.

A detailed performance evaluation was conducted by Lawrie, Klock, and Leverenz.[11] The objective of this study was to determine whether typical microcomputer-based energy analysis programs (modified bin method) could suitably substitute for a detailed energy analysis program such as BLAST or DOE2. Individual envelope elements and internal load effects were isolated through a series of runs that added one component at a time to a building that began as four walls and a roof. Sensitivity to energy conserving retrofits such as adding insulation or reducing glazing were evaluated in a similar way. A comparison between uniform and vendor-supplied weather data was also made.

Another form of benchmark is to compare the computer program results to actual measured data.[12] This method can yield confusing results when occupant effects are considered. On the other hand, to compare computer results to very simple, controlled experimental buildings seems equally compromising. Design of the experiment (what data will be collected and how will the energy studies incorporate assumptions) becomes the overriding consideration.

Criteria and tests must be defined by the user to suit the situation. The literature (including that referenced in this chapter), contains reports of many performance comparisons that focus on the benchmark process from various perspectives--uncertainty

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[11] L. Lawrie, W. Klock, and D. Leverenz, *Evaluation of Microcomputer Energy Analysis Programs*, Technical Report E-193, ADA144684 (USACERL, July 1984).

[12] D. Herron, *Comparison of Building Loads Analysis and System Thermodynamics (BLAST) Computer Program Simulations and Measured Use for Army Buildings*, Technical Report E-174, ADA105162 (USACERL, August 1981).

of input, user effect, limitations of program modeling capacity, and validation efforts.[13] Reviews of these articles, and others, are presented in Appendix A.

Some features seem necessary in any benchmark approach:

1. An EVALUATION STANDARD is essential. A full range of high-quality experimental data would be ideal, but since this does not exist, the best alternative is to use the most reliably validated, detailed tool available. BLAST will do for this purpose. However, it may be advisable to extend previous validation efforts regarding the BLAST program compared to actual data.

2. An INVENTORY OF REQUIRED FEATURES would discriminate between programs that might be adequate and those which may, a priori, be found lacking. Items such as system types, shading calculations, and operation/occupancy scheduling capability would be included in such a list.

3. LOAD COMPONENTS should be compared. This tests the ability to function in a retrofit/energy audit application and identifies the extent to which cancellation of errors contributes to building total consumption. The use of simple, highly determinate test cases is appropriate for this purpose.

4. MONTHLY AND ANNUAL CONSUMPTION should be compared for the same reasons cited in item 3.

5. TEST CASES (BUILDING MODELS) should be drawn from actual facilities. The USACE Standard Designs may be ideal for this purpose.

6. A RANGE OF CLIMATES should be covered. Prior studies have indicated that performance varies with environmental conditions. Benchmarks for each climate should have design features (wall materials/U-values) appropriate to the region. Appendix C contains a climate analysis and proposed set of cases for DOD studies.

7. To reduce user effect, input should be done by committee or reviewed by committee. Input errors should be eliminated as much as possible.

These features could be incorporated in a test methodology that would be centralized and perform a full scope of tests. Table 4 illustrates an example test methodology.

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[13] L. G. Spielvogel, "Comparisons of Energy Analysis Computer Programs," *ASHRAE Journal*, Vol 20, No. 1 (1978); T. Kusuda; B. S. Wagner, "Comparisons of Predicted and Measured Energy Use in Occupied Buildings," *ASHRAE Transactions*, Vol 90, Part 2B (1984); S. C. Diamond, B. D. Hunn, and C. C. Cappiello, "The DOE-2 Validation," *ASHRAE Journal*, Vol 27, No. 11 (1985).

Table 4

Proposed Test Methodology

Phase I:	Develop criteria for satisfactory performance of a candidate program
Phase II:	Select evaluation standard (BLAST) Preliminary design of evaluation report form Limited development of benchmark cases Generation of "standard" results for benchmarks
Phase III:	Trial Application of methodology for a program or a limited number of programs (run benchmark cases, evaluate effectiveness of results and report as discriminators, solve a "typical" design problem to determine whether the evaluation was successful in predicting performance vis a vis BLAST)
Phase IV:	Modify methodology as appropriate on the basis of Phase III Repeat Phase III
Phase V:	Develop and solve remaining benchmark cases
Phase VI:	Implement methodology for independent testing and evaluations
Phase VII:	Consolidate and distribute results of evaluations

6 SUMMARY AND RECOMMENDATIONS

Summary

The suitability of an energy analysis program for USACE designers depends, to a large extent, on the intended application. (Annual energy calculation is more easily predicted than component consumption over a shorter period of time, and whole building consumption is more easily predicted than component consumption.) Thus, fewer programs will be applicable for retrofit studies than for energy budget compliance studies. Rather than switch between programs for each new application, it may be more productive to learn a very detailed program that will be suitable for all applications.

In comparisons of program performance by various reviewers, the following have a significant effect on the outcome of a test:

1. The user
2. The building modeled (simple vs complex)
3. The building site (i.e., climate)
4. Weather data and data format
5. Building occupancy and operation
6. Quantity and degree of ambiguity of available input
7. Time scale of simulation
8. Degree of detail examined (total vs component comparison)
9. Iterative/noniterative nature of simulations.

Studies in which real building data have been compared with multiple simulations between different programs have shown that agreement between programs during evaluation does not guarantee agreement with real data, and further, that prediction averages do not correlate with data. Using one program's output to qualify or validate another program is risky unless the standard program has itself been validated for the particular case in question.

Although a simple study of an idealized building may be a fair comparison of the algorithms involved, it may be misleading to the extent that it rules out user effect. The program's successful solution of a simple problem may not be a good indicator of its ability to give similar accuracy for a complex problem. Understanding the algorithms and how they interact with the user-described model is crucial for success.

Recommendations

The Energy Analysis Calculation Tool Worksheet can help designers choose a tool. Likewise, the designer should follow the guidelines outlined for constructing the building energy analysis model.

The benchmark features (noted in Chapter 5) should be incorporated in a centralized test methodology that would perform a full scope of tests. The methodology would be formed and implemented by a group of users/designers.

The major problems in forming a group such as this methodology would require are resources and user interest. However, using these features and benchmark results (say from BLAST runs of standard designs), individual users could evaluate potential new programs. Documentation of the assumptions in the BLAST runs would be crucial to the success of such a venture.

APPENDIX A:

REVIEWS OF SELECTED LITERATURE

- D. Herron, *Comparison of Building Loads Analysis and System Thermodynamics (BLAST) Computer Program Simulations and Measured Energy Use For Army Buildings*, Technical Report E-174, ADA105162 (U.S. Army Construction Engineering Research Laboratory [USACERL], August 1981).

BLAST models were compared with building data for two Army buildings, a dental clinic and a HQ/classroom building. This project is relevant to the issue of software qualification because of the perspective it offers on attainable accuracy.

It was found that, given sufficiently accurate and complete input data, BLAST could come within about 10 percent of the measured energy use for the two buildings. Larger errors were obtained in simulations involving only as-designed information. Extensive submetering and thorough accounting for all boundary energy are essential in obtaining adequate data. This is not usually possible in practice.

Although comparison to real building performance is essential in verifying software, it does not seem practical, or even productive, to reference software comparisons to performance data that are likely to be incomplete or in error. In view of the success of an iteratively improved BLAST model in simulating these buildings, however, the possibility that the potential usefulness of a program that does badly in a blind test is disguised must be noted.

- L. Lawrie, W. Klock, and D. Leverenz, *Evaluation of Microcomputer Energy Analysis Programs*, Technical Report E-193, ADA144684 (USACERL, July 1984).

Energy analysis programs may be used by COE designers to:

1. Show compliance of a design with energy budgets
2. Evaluate quantitatively the impact of a retrofit option
3. Rank in a relative way several retrofit options.

State-of-the-art mainframe programs such as BLAST and DOE2 reflect the most current technology and have been validated independently a number of times. The proliferating selection of micro-based energy programs is not similarly validated. These programs are generally not as versatile or sophisticated as their mainframe counterparts, but they possess significant ease-of-use qualities that make them attractive to COE designers.

This report demonstrates an attempt to compare two typical micro-based energy programs using BLAST as a reference standard. Four aspects of performance are considered:

1. Annual energy consumption (total, heating/cooling)
2. Evaluation of retrofit items

3. Effect of modeling capability deficiencies and substitute weather data

4. Judgmental input requirements.

The selected programs were SASEAP (Sud and Assoc.) and OPCOST (Carrier), both modified bin method programs.

The problem of evaluating the effect of algorithm is noted. Since most programs are proprietary, the inner workings of the algorithm cannot be inspected.

Evaluation Methodology:

-Use BLAST as a reference standard to measure micro programs

-Make input as uniform as possible (to minimize the user effect)

-Perform two series of trials for each of three climatically distinct locations

Test Plan:

The first series of tests deals only with details that both of the programs can handle. Starting with a bare box model, a simple building is built up detail by detail. The completed model is then retrofitted with a number of energy-saving modifications one at a time and collectively.

The sequence of steps in the build-up is:

1. Walls/Roof

2. +Slab floor

3. +South glazing

4. +Full glazing

5. +Ventilation/Infiltration

6. +Internal loads (people, lights, equipment)

The sequence of retrofits is:

1. Reduce ventilation/infiltration

2. Add storm windows

3. Add wall/ceiling insulation

4. Reduce glazed area

5. Combine 1 through 4.

The second series of trials uses vendor-supplied weather data and a retrofit package that includes more glass, a night/weekend setback on the thermostat, and overhangs. The micro programs did not have the capability to model overhangs.

The following points were compared:

1. Accuracy of predictions with respect to BLAST

2. Energy savings due to retrofits

3. Ranking of retrofit items.

Results in brief:

Variance in results was found to be a strong function of both the program and the location.

The substitution of vendor weather for the initially uniform data produced significantly greater variation in micro program output than did the substitution of Test Reference Year (TRY) for Typical Meteorological Year (TMY) data in BLAST.

The micro programs ranked the value of retrofit items successfully, but did not predict the resultant energy savings satisfactorily.

The micro programs did not calculate yearly energy use well enough to be acceptable for testing compliance with Design Energy Targets (DETs).

- W. Bahnfleth, D. Herron, and K. Ruby, *Evaluation of Building Design/Analysis Software for Microcomputers*, Technical Report E-88/01, ADA188134 (USACERL, November 1987).

This project complements the work described above by comparing "ease of use" aspects of a number of load and duct design tools.

The points reviewed in the study were:

1. Input procedure

2. Output reports

3. Documentation

4. Support and training.

In addition, available modeling features and costs were summarized. Results of a simple calculation were compared.

Experience gained in this work made it clear that, except in cases of gross mismatch, it is not possible to rank programs on the basis of features other than the accuracy of the algorithms. A feature that may be useful or essential to one user may be useless to another. The apparent conclusion is that some features of a program may be given a meaningful comparison by persons other than the end user while others may not (i.e., algorithmic accuracy is an absolute while "user-friendly" and "sufficiently flexible" are in the eye of the user).

Comparisons of test model results showed that algorithmic differences in load programs were expressed in a consistent way. Differences in duct sizing results could not be explained with similar ease.

- T. Kusuda, "Standards Criteria for HVAC Systems and Equipment Performance Simulation Procedures," *ASHRAE Journal*, Vol 23, No. 10 (1981).

This article discusses the problem of developing a standard evaluation technique for energy programs, particularly, the problem of HVAC system simulation.

Three simulation types are identified: truly dynamic, quasi-steady heat/mass balance, quasi-dynamic.

Conclusions include:

1. An ideal program allows user defined systems

2. Data for validation are very scarce

3. Criteria should be tailored to the application and degree of sophistication of the program. Special systems (ice storage or solar) should be evaluated separately. Development of characteristic problems is recommended for verification of algorithmic accuracy (as a substitute for line-by-line review of the code).

- L. G. Spielvogel, "Comparisons of Energy Analysis Computer Programs," *ASHRAE Journal*, Vol 20, No. 1 (1978).

This article discusses results of an Automated Procedures for Engineering Consultants (APEC) symposium project and additional work undertaken by the author. A group of users tested a number of programs on a sample problem. Spielvogel later used all the programs to run another example.

He points out that different user/program combinations lead to different results. The possible permutations include:

1. Multiple users/multiple programs

2. Multiple users/single program

3. Single user.

Several comparison/validation pitfalls were noted:

1. Specificity of comparison to the problem chosen

2. The "average" result in a group comparison is not necessarily the most correct

3. Agreement on simple problems can be misleading since more complex situations will require more user interpretation of input.

The overall impression is that a given program can produce any number of results in the course of a validation study--a useful caveat if it is used constructively.

- G. A. Reeves, C. P. Robart, Jr., and E. Stamper, "Crosschecking Energy Analysis Procedures and Standardizing Weather Input," *ASHRAE Transactions*, Vol 82, Pt. 1 (1976).

This is a report of the "Computer Users' Subcommittee" of the Task Group (TG) on Energy Requirements for Heating and Cooling Off Buildings. The primary issue addressed in this communication is the standardization of weather data for hourly energy analysis programs.

Two "crosschecking" procedures were executed:

1. Five programs were exercised by their respective owners using a hypothetical building design, 10 years of weather, and the TRY selected from these data. The average of the 10 years was compared to the TRY result and to a calculation made by a NOAA meteorologist. A second comparison to the U.S. Postal Service Program was also conducted.

2. Comparisons of purchased energy predictions for an actual building at Ohio State University (OSU) against the OSU program and building data.

The hypothetical simulation (which did not include system modeling) indicated good agreement on average monthly peak demand and yearly total load (worst case, approx. +/- 10 percent of 10-y avg.).

The results for the real building, however, varied widely for a number of reasons:

1. Weather data taken on the building site were not consistent with the TG's methodology, so acceptable data from the nearest airport were used instead.

2. As-designed and as-operated conditions differed significantly. The choice of conditions was left to the users, who were divided as to which set to include in their models.

3. Not all of the programs could model the complicated dual duct, terminal reheat system supplemented by outside air controlled perimeter ceiling radiation.

Compared to the OSU program, which had been validated for this building, the commercial programs deviated by as much as +/- 50 percent on gas usage, were 3-9 percent high on annual electric usage, and 11-45 percent high on September electric demand.

These results reinforce the points made in the Spielvogel article. Validation of individual programs against real buildings is absolutely necessary, but the comparison of programs on the basis of a complex model representative of a real building may be misleading since it is subject to much larger uncertainties (which are seldom quantifiable and usually never quantified in the literature.)

- A. W. Black, "Is Bigger Really Better? A Heretical View of Computer Energy Progr ms," *ASHRAE Journal*, Vol 20, No. 1 (1978).

This article showed that hand calculations and simplified computer calculations are just as good for energy analysis as complex hour-by-hour programs. Given the point in time when it was made, this remark has a certain validity. A yearly energy calculation is the integral of the load curve, and thus, smooths out the effect of errors in the instantaneous load estimate so long as a reasonable first law balance is maintained for the building. Since energy and load functions are now combined in the larger programs, the current situation is different.

Nevertheless, the author makes some good observations regarding simulation:

1. Although hourly simulation may be adequate from the perspective of envelope response and environmental changes, it is not able to capture the transients that are associated with duty cycling of thermal equipment--on the order of minutes.

2. The importance of input quality deserves consideration. At the level of considering design alternatives, a reasonable ranking of effects is sufficient. For a study of an operating building, absolute accuracy is needed, therefore, detailed and accurate input is also required.

3. An argument on behalf of bin methods is made on the basis of the smoothing effect of this method on weather data. Anomalous data are not exaggerated in importance. The author also states, on the basis of his experience, that weather format is one of the least significant factors in accurate energy use prediction, provided that the chosen format is used correctly.

- B. S. Wagner, "Comparisons of Predicted and Measured Energy Use in Occupied Buildings," *ASHRAE Transactions*, Vol 90, Pt. 2B (1984).

This article compares the results of a number of validation studies for various detailed mainframe energy programs (e.g., BLAST, DOE-2, NBSLD, REAP) performed by different investigators. Concerns of the author included the following:

1. Effect of level of input detail in modeling an existing building

2. Effect of skill level of user

3. Effect of input revision based on an initial comparison

4. Effect of time scale of comparison (i.e., is performance evaluated over a period of several days, months, or a year?)

5. Effect of building occupancy.

The author notes that the ability to model an empty building does not imply the ability to accurately model the same building during occupancy. Results of studies showing variations in energy consumption of from 2:1 to 40:1 for identical buildings or apartments are cited. The need for accurately modeling occupant behavior is noted (it is an objective of the study to determine whether current capabilities are adequate).

Use of controlled model testing to identify particular jobs for which a program is suited is discussed (e.g., a program may be suitable for energy audits or retrofit calculations, but not for research).

Validation studies are classified in two ways:

1. By the manner in which the model is developed

2. By the type of input data available.

The types of model development considered are:

1. Noniterative--blind simulations without knowledge of real building operating characteristics. The author describes this as a test of model accuracy and user skill. The real-life situation closest to this type of test is the design of a new building.

2. Verifiable input/measurement errors corrected. In this case, changes to input that could be justified independently of their effect on model prediction were made. The corresponding real-life situation would be an energy audit or the preparation of a model for a retrofit study.

3. Models verified by comparison to a building that was used in the development of the program.

4. Iterative models--those in which results were based on corrections to input solely for the purpose of bringing data and prediction into agreement. (It is noted that this is not a type of validation study.)

Input accuracy is classified as follows:

Class A: Detailed on-site monitoring.

Class B: Submetered HVAC equipment, indoor temperature, on-site outdoor temperature, appliance load.

Class B-: Submetering, off-site weather or no indoor temperature or no appliance load.

Class C: No submetering.

Class X: Averaged characteristics of a group of buildings or normalized weather.

Class D: Major input items missing (e.g., weather).

Results and conclusions of the comparison indicated the following:

1. Exclusive of Class D input, the study results fell within +/- 20 percent of measured performance when occupied. Statistics for unoccupied buildings were only slightly better. The author notes that groups of occupied buildings or units within tend to cancel out individual occupant effects. Furthermore, although unoccupied buildings are usually monitored better than occupied buildings, the observation periods in such cases are frequently of shorter duration, hence the unexpectedly small difference in scatter among these studies.

2. Heating energy requirements were predicted more accurately than cooling energy and retrofit energy savings.

3. For detailed models (BLAST, REAP, DOE-2), it appears that input correction, when possible, can result in agreement consistently within 20 percent, and as good as 10 percent. However, blind studies using these programs gave errors as great as 60 percent.

4. Two methods that successfully reduced errors were identified:

a. Correction of verifiable errors on the basis of actual data. This is recommended as standard practice for audits and retrofits.

b. For groups of buildings with limited data, restrict comparisons to the group average.

- S. C. Diamond, B. D. Hunn, and C. C. Cappiello, "The DOE-2 Evaluation," *ASHRAE Journal* (November 1985).

This article describes a study of user effects on energy analyses performed with DOE2.1A. Four buildings were simulated by each of five or six experienced users for three types of input. The simulations were all "blind" (i.e., there was no correction based on comparison of predicted and measured results).

The test buildings were:

1. Single floor insulated frame office building in Santa Clara, CA (6700 sq ft)

2. Multifloor office with granite block walls and one glass wall in Dayton, OH (20000 sq ft)

3. Retail store with precast concrete walls in Albuquerque, NM (33000 sq ft)

4. Restaurant with hollow-core concrete block walls in Downers Grove, IL (16300 sq ft).

These buildings represent a variety of construction types, climatic regions, and load types.

The three types of data provided were classified as:

1. Uncontrolled--no data missing in typical design documents were provided, ambiguous data were resolved by the user, and no user questions were answered.

2. Refined--missing data were supplied, user questions were answered, and "verifiable errors" were corrected. The users were not, however, given suggestions to change a particular input variable, rather, a group of variables to be examined was indicated.

3. SET-- the 'standard evaluation technique' then intended to be part of the BEPS (Building Energy Performance Standards) program. This method is intentionally as well defined as possible, and includes specified operating conditions, weather, and other conditions.

Results are presented in the form of root mean square (rms) scatter among the group of users. No building data were compared with the simulations. For the uncontrolled input case, monthly total energy use varied by as much as a factor of two from user to user. The use of refined input reduced the error by a factor of as much as 2.5. The use of the SET resulted in further reduction in some cases, but little in others. The authors believe that uncertainty in fuel energy demand was considerably greater in the refined data comparisons than in the SET. Consequently, fuel dominated buildings showed more improvement than electric dominated buildings when the SET was used.

The authors' conclusions are:

1. Scatter in results is reduced through the use of refined data. Reductions were from 19 to 63 percent from uncontrolled data to refined data. Further improvement occurs in going from refined data to SET, but not as much. (The authors noted that refinement of data resulted in some reordering of users, indicating that errors due to uncontrolled data were essentially random.)

2. In the majority of cases, fuel energy consumption was subject to greater uncertainty than was electric consumption. Scatter remains larger regardless of the level of input refinement.

3. Considerable scatter must be expected, even among expert users, when input is uncontrolled. Independent checking for input errors and elimination of input ambiguities results in the greatest reduction of "user effect."

It should be noted that the models compared in this study are rather detailed and that the buildings and systems are realistic in their complexity of construction and operation. A "tolerable" amount of scatter in a study of this sort is probably not acceptable in the case of a "box study" such as that made by Lawrie, Klock, and Loverenz described previously.

- J. W. Coaker, "Software Management: Caveat Emptor," *Proceedings of the ASME Conference on Computers in Engineering*, Vol 4 (ASME, 1982).

The author makes a case for end-user responsibility for the outcome of computer design tool use. His background is in pressure vessel calculations, but his remarks are generic to the simulation field.

Verification, validation, and qualification (V/V/Q) are defined and discussed. Problems with the efforts of technical societies such as ASME to conduct V/V/Q programs are mentioned, especially, liability and the inability to endorse the outcome of a comparison. The author contends that such bodies cannot, despite their good intentions, account for the understanding of the user, appropriateness of input/output, or application. Therefore, the user must be skilled in V/V/Q.

Several other problems are mentioned: poor documentation, sales personnel that are not technically skilled in the products they sell, poor or nonexistent program maintenance.

- H. P. Richter, "Verifying the Reliability of Engineering Software," *Computers in Mechanical Engineering* (January 1984).

This article resembles that of Coaker. It discusses software problems resulting from inadequate documentation and validation. Richter gives his views on the format of verification reports and procedures for maintaining current documentation. Most of this information would apply to the authors of a program, not the end users. However, the point is made that responsibility for verification does fall on the user to a certain extent if the documentation is faulty or missing, if an unqualified application is desired, or even if a different computer system from the one used in prior verifications is to be used.

Perhaps the most interesting issue raised by this article concerns the verification status of the many commercial programs. This aspect of program evaluation addressed is not raised in reviews, nor do HVAC software firms offer verification reports for inspection by potential customers.

- F. Y. Sorrell, T. J. Luckenbach, and T. L. Phelps, "Validation of Hourly Building Energy Models for Residential Buildings," *ASHRAE Transactions*, Vol 91, Pt. 2b (1985).

The authors compared the performance of DOE 2.1B, EMPS 2.1, and TARP84 to data taken from a number of test houses. The period over which measurements were made varied from 1 day to 6 weeks.

The following requirements were established for the data base:

- measured on-site weather

- measured infiltration for a variety of conditions

- unoccupied conditions

- measured interior temperature

- measured HVAC system performance or coil loads or both.

The restriction to unoccupied conditions was motivated by the authors' conclusion that previous studies involving occupied buildings were compromised by the inability to track the behavior of occupants with sufficient accuracy.

The results showed that low thermal mass cases were predicted more accurately than high thermal mass and high insulation cases. The programs tended to agree better with one another than with the measurements, and agreement with measurements improved as the time span of the simulation was lengthened (as a result of averaging).

- T. Kusuda, "A Comparison of Energy Calculation Procedures," *ASHRAE Journal*, Vol 23, No. 8 (1981).

Seven users compared seven large-scale simulation programs to the manual method proposed by ASHRAE TC 4.7. The most interesting finding from the point of view of this review was that differences between users were greater than differences between programs. This resulted in part from the use of fairly complicated test cases which required a fair amount of judgmental input by the user.

- A. J. Willman, "Development of an Evaluation Procedure for Building Energy Design Tools," *Proceedings of the Building Energy Simulation Conference*, Seattle, WA (1985).

This paper briefly describes an energy software evaluation procedure developed by the Building Design Tool Council (BDTC). Although performance as compared with supplied data is included in the procedure, the author distinguishes it from a validation.

A preliminary step was the development of a categorization strategy based on some 50 published surveys. The method generates a tree structure with the most general descriptors at the top and finer discriminators at lower levels. This could be helpful to a potential user as well as to the creator of an evaluation procedure.

The evaluation and testing procedure has three underlying assumptions:

1. Equal weight should be given to user features and technical capabilities. BDTC felt that user features had been overlooked in other evaluations and that they are very significant in determining the degree of utilization of a tool.

2. Standard numerical data sets for annual energy use by typical residential and commercial buildings should be included in the technique.

3. The evaluation should only be performed by a person with an extensive background in design tool use.

The procedure was published as three major sections:

1. User utility characteristics (application, building type, availability, cost of use, user information, I/O, and status of comparative testing)

2. Technical capability characteristics (heat transfer, computation basis, time steps, loads and profiles, passive solar simulation, HVAC system simulation, output reports, and benchmark comparisons)

3. Final report (brief summary, detailed checklist of characteristics, and narrative summary of all tool features)

The "key characteristics list" that is included in the summary covers seven major features: category of tool, primary application, applicable building type, form of tool availability, conventional simulation capability, alternative energy simulation capability, and price.

- *Guidance on Software Package Selection*, S. Frankel, Ed., National Bureau of Standards (NBS) Special Publication C 13.10:500-144.

This is a comprehensive guide to selecting, purchasing, and installing software packages. The software under discussion is the type that might be used to track requisitions, payroll, or other office support functions. For this reason, the methodology discussed deals with the problems of integrating the system into an office environment of technical, clerical, system, and management personnel. The case of a software tool acquired for use by a limited number of technical personnel is not really the subject of this document. Nevertheless, many important points that do have some bearing on the selection of technical software are considered.

The following components of the selection process are identified:

- requirements analysis

- requirements document

- identification of candidate packages

- assessment of support needs

- package selection

- contract negotiation

- package installation

- package testing.

The requirements analysis is conducted by a team affected by the software. Their task is to define current procedures, identify constraints, and estimate the life of the package. Package requirements are stated formally in a requirements document that provides a basis for comparing candidate packages. The requirements document may include requirements for:

- package functions

- inputs

- outputs

- user interface

- technical characteristics

- documentation

- training

- installation

- maintenance.

Requirements suggested for documentation are: a comprehensive index, a technical level appropriate to intended users, adequately detailed discussion of all commands and features related to the application, systematic organization, and updates to reflect the current state of the package.

Candidate packages are to be chosen by a selection team. The following sources of candidates are suggested: application journals, compendia of software, search firms, consultants, and other users. The suggested selection process is one of elimination on the basis of comparison to the requirements document. It is also suggested that the buyer obtain profiles of both the vendor and the developer of the software. Some of the criteria for narrowing the field of candidate packages are:

- hardware or operating system incompatibility

- excessive memory requirements

- requirements document criteria

- cost-benefit analysis results (including personnel, purchase, implementation, and maintenance costs)

- support assessment: documentation, installation, training, maintenance (warranty, upgrades, consulting, modifications, and user groups).

The discussion of package testing centers on how the package will function within the office/organizational structure. This is not the major concern for a technical tool.

APPENDIX B:

BLAST Review Report

```
*******************************************************************************
**                                                                           **
**                   R E V I E W   S U M M A R Y   R E P O R T               **
**                                                                           **
*******************************************************************************
 1 BUILDING  WITH  11 ZONES                            SIMULATION PERIOD =  1 JAN 1968 - 31 DEC 1968
 1 SYSTEM                                              LOCATION = COLUMBIA, MO 1968 TRY
 1 PLANT                                               HEATING DEGREE DAYS = 5142.0
OUTPUT UNITS IN ENGLISH                                COOLING DEGREE DAYS = 1239.5
                                                       GROUND TEMPS = 62,61,62,65,68,71,75,75,71,68,65,62
PROJECT = FT HOOD DENTAL CLINIC


    FOR ZONE 1000 "CRAWL SPACE                         ", FLOOR AREA      9384.00 FT**2
         CEILING HEIGHT         2.5 FT        APPROXIMATED VOLUME       23451. FT**3

    FOR ZONE    1 "NORTH LAB                           ", FLOOR AREA       589.00 FT**2
         CEILING HEIGHT         9.0 FT        APPROXIMATED VOLUME        5301. FT**3

    FOR ZONE    2 "NORTH WEST LAB                      ", FLOOR AREA       266.00 FT**2
         CEILING HEIGHT         9.0 FT        APPROXIMATED VOLUME        2394. FT**3

    FOR ZONE    3 "WEST OPER RMS                       ", FLOOR AREA      1330.00 FT**2
         CEILING HEIGHT         9.0 FT        APPROXIMATED VOLUME       11970. FT**3

    FOR ZONE    4 "LOCKER RMS                          ", FLOOR AREA       767.00 FT**2
         CEILING HEIGHT         9.0 FT        APPROXIMATED VOLUME        6903. FT**3

    FOR ZONE    5 "LIBRARY CONF RMS                    ", FLOOR AREA       684.00 FT**2
         CEILING HEIGHT         9.0 FT        APPROXIMATED VOLUME        6156. FT**3

    FOR ZONE    6 "WAITING ROOM                        ", FLOOR AREA       771.00 FT**2
         CEILING HEIGHT         9.0 FT        APPROXIMATED VOLUME        6939. FT**3

    FOR ZONE    7 "RECORDS AND SUPPLY                  ", FLOOR AREA       923.50 FT**2
         CEILING HEIGHT         9.0 FT        APPROXIMATED VOLUME        8311. FT**3

    FOR ZONE    8 "XRAY                                ", FLOOR AREA       974.00 FT**2
         CEILING HEIGHT         9.0 FT        APPROXIMATED VOLUME        8766. FT**3

    FOR ZONE    9 "SOUTH OPER RMS                      ", FLOOR AREA      1242.00 FT**2
         CEILING HEIGHT         9.0 FT        APPROXIMATED VOLUME       11178. FT**3

    FOR ZONE   10 "EAST OPER RMS                       ", FLOOR AREA      1050.00 FT**2
         CEILING HEIGHT         9.0 FT        APPROXIMATED VOLUME        9450. FT**3
```

****

***** BUILDING ENVELOPE DATA *****

****

NOTE ** SURFACES IN ZONES DESIGNATED AS ATTIC OR CRAWLSPACE ARE NOT INCLUDED

*NORTH= 0.
EAST= 90.0

	AREA (FT**2)	U (B/H*F**2*R)	AZIMUTH* (DEGREES)	TILT (DEGREES)	PER CENT GLAZING
ROOF	8596.50	0.072	*****	0.0	0.0
ROOF1	8596.50	0.072	*****	0.0	
EXTERIOR WALL	405.00	0.369	0.0	90.0	14.0
EWALL1	295.11	0.267	0.0	90.0	
SINGLE PANE TINTED WINDOW	56.61	1.115	0.0	90.0	
WINDOW PANEL	53.28	0.141	0.0	90.0	
EXTERIOR WALL	864.00	0.432	180.0	90.0	21.3
EWALL1	573.02	0.267	180.0	90.0	
SINGLE PANE TINTED WINDOW	184.42	1.115	180.0	90.0	
WINDOW PANEL	106.56	0.141	180.0	90.0	
EXTERIOR WALL	922.50	0.375	270.0	90.0	14.0
EWALL1	713.17	0.267	270.0	90.0	
SINGLE PANE TINTED WINDOW	129.42	1.115	270.0	90.0	
WINDOW PANEL	79.92	0.141	270.0	90.0	
EXTERIOR WALL	751.50	0.399	90.0	90.0	17.2
EWALL1	542.17	0.267	90.0	90.0	
SINGLE PANE TINTED WINDOW	129.41	1.115	90.0	90.0	
WINDOW PANEL	79.92	0.141	90.0	90.0	
FLOOR OVER CRAWL SPACE	8596.50	0.159	*****	180.0	0.0
FLOOR1	8596.50	0.159	*****	180.0	
	======	=====			=====
	20136.00	0.397 (OVERALL WALL AVERAGE)			17.0 PERCENT OF TOTAL WALL AREA
		0.156 (BUILDING OVERALL AVERAGE)			5.8 PERCENT OF TOTAL FLOOR AREA

FLOOR AREA OF BUILDING	=	8596.50	FT**2
APPROX EXTERIOR SURFACE AREA	=	20136.00	FT**2
APPROXIMATE VOLUME	=	77367.49	FT**3
APPROX VOLUME / FLOOR AREA	=	9.0	FT (APPROXIMATE BUILDING WALL HEIGHT)

****
*** SURFACE CONSTRUCTIONS ***
****

	U WITHOUT FILM COEFF (B/H*F**2*R)	
CPCEIL	0.202	
FINISH FLOORING - TILE 1 / 16 IN		19.808
C10 - 8 IN HW CONCRETE		1.499
B1 - AIRSPACE RESISTANCE		1.099
B2 - 1 IN INSULATION		0.301
CPFLOOR	0.100	
DIRT 12 IN		0.100
CPWALL	0.977	
A1 - 1 IN STUCCO		4.802
C10 - 8 IN HW CONCRETE		1.499
E1 - 3 / 4 IN PLASTER OR GYP BOARD		6.720
EWALL1	0.345	
BRICK - FACE 4 IN		2.312
CONCRETE - CEMENT MORTAR 1 / 2 IN		9.976
CONCRETE - CEMENT MORTAR 1 / 2 IN		9.976
CONCRETE - CEMENT MORTAR 1 / 2 IN		9.976
CONCRETE - CEMENT MORTAR 1 / 2 IN		9.976
C3 - 4 IN HW CONCRETE BLOCK		1.411
B1 - AIRSPACE RESISTANCE		1.099
BLBD - GYPSUM PLASTER 1 / 2 IN		2.249
SINGLE PANE TINTED WINDOW	21.186	
GLASS - GREY PLATE 1 / 4 IN		21.186
WINDOW PANEL	0.160	
GLASS - HEAT ABSORBING PLATE 1 / 2 IN		10.593
INS - CELLULAR GLASS 2 IN		0.200
C3 - 4 IN HW CONCRETE BLOCK		1.411
BLBD - GYPSUM PLASTER 1 / 2 IN		2.249
PWALL2	0.405	
C8 - 8 IN HW CONCRETE BLOCK		0.900
B1 - AIRSPACE RESISTANCE		1.099
BLBD - GYPSUM PLASTER 1 / 2 IN		2.249
PWALL1	0.556	
BLBD - GYPSUM PLASTER 1 / 2 IN		2.249
B1 - AIRSPACE RESISTANCE		1.099
BLBD - GYPSUM PLASTER 1 / 2 IN		2.249

****
*** SURFACE CONSTRUCTIONS ***
****

	U WITHOUT FILM COEFF (B/H*F**2*R)	
ROOF1	0.076	
E2 - 1 / 2 IN SLAG OR STONE		19.904
E3 - 3 / 8 IN FELT AND MEMBRANE		3.514
A3 - STEEL SIDING		5200.000
E4 - CEILING AIRSPACE		1.000
B4 - 3 IN INSULATION		0.100
E5 - ACOUSTIC TILE		0.560
FLOOR1	0.202	
B2 - 1 IN INSULATION		0.301
B1 - AIRSPACE RESISTANCE		1.099
C10 - 8 IN HW CONCRETE		1.499
FINISH FLOORING - TILE 1 / 16 IN		19.808

```
**************************
***  FAN SYSTEM DATA  ***
**************************

SYSTEM   1  MULTIZONE          MAIN FAN SYSTEM

SERVING ZONES:   1,  2,  3,  4,  5,  6,  7,  8,  9, 10


     MIXED AIR CONTROL = FIXED AMOUNT                       DESIRED MIXED AIR TEMP = COLD DECK TEMP
     FIXED OUTSIDE AIR VOLUME =  -114 FT**3/MIN
     COLD DECK CONTROL = FIXED SET POINT                    COLD DECK FIXED TEMP   =  60 DEG. F
     HOT  DECK CONTROL = OUTSIDE AIR CONTROL                HOT  DECK CONTROL SCHEDULE = ( 120 AT   10 ,   80 AT   70) DEG. F

     SYSTEM OPERATION =ON,01JAN THRU 31DEC                  EXHAUST FAN OPERATION =ON,01JAN THRU 31DEC
     PREHEAT COIL OPERATION =ON,01JAN THRU 31DEC            HEATING COIL OPERATION = OFF, 1APR THRU 30SEP
     COOLING COIL OPERATION =ON,01JAN THRU 31DEC            HUMIDIFIER OPERATION =ON,01JAN THRU 31DEC
     HEAT RECOVERY OPERATION = OFF,01JAN THRU 31DEC         MINIMUM VENTILATION SCHEDULE = MINOA,01JAN THRU 31DEC
     SYSTEM ELECTRICAL DEMAND SCHEDULE =ON,01JAN THRU 31DEC
```

ZONE	SUPPLY AIR VOLUME FT**3/MIN	MINIMUM AIR FRACTION	EXHAUST AIR VOLUME FT**3/MIN	REHEAT CAPACITY 1000BTU	BASEBOARD HEAT CAPACITY 1000BTU	RECOOL CAPACITY 1000BTU	ZONE MULTIPLIER
1	1.784E+03	0.10	1.000E+03	0.000E+00	0.000E+00	0.000E+00	1
2	4.060E+02	0.10	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1
3	2.010E+03	0.10	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1
4	7.610E+02	0.10	6.000E+02	0.000E+00	0.000E+00	0.000E+00	1
5	5.020E+02	0.10	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1
6	8.330E+02	0.10	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1
7	8.840E+02	0.10	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1
8	8.290E+02	0.10	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1
9	2.245E+03	0.10	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1
10	2.105E+03	0.10	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1

***** PLANT/EQUIPMENT DATA *****

PLANT 1 HEATING PLANT

SERVING SYSTEMS: 1

EQUIPMENT TYPE	SIZE 1000BTU	OPER HOURS	MAX LOAD 1000BTU	AVERAGE OPER RATIO	PEAK OPER RATIO	PERCENT HOURS AT PEAK	CHILLER COP OR BOILER EFF (AVERAGE)
BOILER	100	4392	100	0.470	1.00	41	0.72

***** SCHEDULED LOADS *****

ZONE NUMBER	FROM	THRU	SCHEDULE	DESIGN PEAK LOAD		DESIGN PEAK LOAD PER FT**2	# HOURS PER WEEK	AVERAGE LOAD WHEN LOAD SCHEDULED	
PEOPLE:									
1	1JAN	31DEC	ALL ZONES PEOPLE	4.00	PEOPLE	6.791E-03	50.0	2.620E+00	PEOPLE
2	1JAN	31DEC	ALL ZONES PEOPLE	2.00	PEOPLE	7.519E-03	50.0	1.310E+00	PEOPLE
3	1JAN	31DEC	ALL ZONES PEOPLE	11.0	PEOPLE	8.271E-03	50.0	7.205E+00	PEOPLE
4	1JAN	31DEC	ALL ZONES PEOPLE	2.00	PEOPLE	2.608E-03	50.0	1.310E+00	PEOPLE
5	1JAN	31DEC	ALL ZONES PEOPLE	4.00	PEOPLE	5.848E-03	50.0	2.620E+00	PEOPLE
6	1JAN	31DEC	ALL ZONES PEOPLE	31.0	PEOPLE	4.021E-02	50.0	2.031E+01	PEOPLE
7	1JAN	31DEC	ALL ZONES PEOPLE	7.00	PEOPLE	7.580E-03	50.0	4.585E+00	PEOPLE
8	1JAN	31DEC	ALL ZONES PEOPLE	5.00	PEOPLE	5.133E-03	50.0	3.275E+00	PEOPLE
9	1JAN	31DEC	ALL ZONES PEOPLE	11.0	PEOPLE	8.857E-03	50.0	7.205E+00	PEOPLE
10	1JAN	31DEC	ALL ZONES PEOPLE	8.00	PEOPLE	7.619E-03	50.0	5.240E+00	PEOPLE
LIGHTS:									
1	1JAN	31DEC	CLINIC LIGHTS AND EQUIPMENT	5.73	1000BTU	9.728E-03	168.	2.878E+00	1000BTU
2	1JAN	31DEC	CLINIC LIGHTS AND EQUIPMENT	2.18	1000BTU	8.195E-03	168.	1.095E+00	1000BTU
3	1JAN	31DEC	CLINIC LIGHTS AND EQUIPMENT	7.14	1000BTU	5.368E-03	168.	3.586E+00	1000BTU
4	1JAN	31DEC	CLINIC LIGHTS AND EQUIPMENT	3.96	1000BTU	5.163E-03	168.	1.989E+00	1000BTU
5	1JAN	31DEC	CLINIC LIGHTS AND EQUIPMENT	3.28	1000BTU	4.795E-03	168.	1.647E+00	1000BTU
6	1JAN	31DEC	CLINIC LIGHTS AND EQUIPMENT	2.73	1000BTU	3.541E-03	168.	1.371E+00	1000BTU
7	1JAN	31DEC	CLINIC LIGHTS AND EQUIPMENT	4.37	1000BTU	4.732E-03	168.	2.195E+00	1000BTU
8	1JAN	31DEC	CLINIC LIGHTS AND EQUIPMENT	3.96	1000BTU	4.066E-03	168.	1.989E+00	1000BTU
9	1JAN	31DEC	CLINIC LIGHTS AND EQUIPMENT	9.28	1000BTU	7.472E-03	168.	4.660E+00	1000BTU

****
*** SCHEDULED LOADS ***
****

ZONE NUMBER	FROM	THRU	SCHEDULE	DESIGN PEAK LOAD		DESIGN PEAK LOAD PER FT**2	# HOURS PER WEEK	AVERAGE LOAD WHEN LOAD SCHEDULED	
LIGHTS:									
10	1JAN	31DEC	CLINIC LIGHTS AND EQUIPMENT	6.41	1000BTU	6.105E-03	168.	3.219E+00	1000BTU
ELECT EQUIP:									
1	1JAN	31DEC	CLINIC LIGHTS AND EQUIPMENT	10.2	1000BTU	1.739E-02	168.	5.143E+00	1000BTU
2	1JAN	31DEC	CLINIC LIGHTS AND EQUIPMENT	6.82	1000BTU	2.564E-02	168.	3.425E+00	1000BTU
3	1JAN	31DEC	CLINIC LIGHTS AND EQUIPMENT	3.41	1000BTU	2.564E-03	168.	1.713E+00	1000BTU
4	1JAN	31DEC	CLINIC LIGHTS AND EQUIPMENT	0.000E+00	1000BTU	0.000E+00	168.	0.000E+00	1000BTU
5	1JAN	31DEC	CLINIC LIGHTS AND EQUIPMENT	3.41	1000BTU	4.985E-03	168.	1.713E+00	1000BTU
6	1JAN	31DEC	CLINIC LIGHTS AND EQUIPMENT	1.82	1000BTU	2.361E-03	168.	9.140E-01	1000BTU
7	1JAN	31DEC	CLINIC LIGHTS AND EQUIPMENT	3.41	1000BTU	3.692E-03	168.	1.713E+00	1000BTU
8	1JAN	31DEC	CLINIC LIGHTS AND EQUIPMENT	28.9	1000BTU	2.964E-02	168.	1.450E+01	1000BTU
9	1JAN	31DEC	CLINIC LIGHTS AND EQUIPMENT	3.41	1000BTU	2.746E-03	168.	1.713E+00	1000BTU
10	1JAN	31DEC	CLINIC LIGHTS AND EQUIPMENT	3.41	1000BTU	3.248E-03	168.	1.713E+00	1000BTU
GAS EQUIP:									
2	1JAN	31DEC	CLINIC LIGHTS AND EQUIPMENT	5.00	1000BTU	1.880E-02	168.	2.511E+00	1000BTU

NO OTHER EQUIP LOADS:

****
*** INFILTRATION AND VENTILATION ***
****

NUMBER	FROM	THRU	OCCUPIED MAX	OCCUPIED MIN	UNOCCUPIED MAX	UNOCCUPIED MIN	SPECIFIED PEAK FLO

NO INFILTRATION:

NO NATURAL VENTILATION:

****
***   MECHANICAL VENTILATION   ***
****

NUMBER	FROM THRU		OCCUPIED MAX	OCCUPIED MIN	UNOCCUPIED MAX	UNOCCUPIED MIN	PEAK FLOW
OUTSIDE AIR:							
SYS 1	1JAN THRU 31DEC, DEFAULT VENTILATION SCHEDULE	FT**3/MIN	4.1E+03	4.1E+03	4.1E+03	4.1E+03	4.1E+03
		MO/DA/HR	1/ 2/ 8	1/ 2/ 8	1/ 1/ 1	1/ 1/ 1	

****
*** SPACE TEMPERATURES DEG. F   ***
****

ZONE NUMBER	CONTROLS	HEATING OCCUPIED MAX	HEATING OCCUPIED MIN	HEATING UNOCCUPIED MAX	HEATING UNOCCUPIED MIN	COOLING OCCUPIED MAX	COOLING OCCUPIED MIN	COOLING UNOCCUPIED MAX	COOLING UNOCCUPIED MIN	NO HEATING OR COOLING OCCUPIED MAX	NO HEATING OR COOLING OCCUPIED MIN	NO HEATING OR COOLING UNOCCUPIED MAX	NO HEATING OR COOLING UNOCCUPIED MIN
1000	*****NO CONTROLS*****	******	******	******	******	******	******	******	******	******	******	76.52	64.4
1	CLINIC CONTROLS	******	******	68.00	67.93	69.88	68.02	69.18	68.00	******	******	68.00	68.0
2	CLINIC CONTROLS	******	******	68.00	67.81	85.29	66.37	77.96	68.00	******	******	68.00	68.0
3	CLINIC CONTROLS	68.00	67.77	68.00	67.70	69.86	68.00	69.63	68.00	68.00	68.00	68.00	68.0
4	CLINIC CONTROLS	68.00	67.93	68.00	67.88	69.59	68.00	69.20	68.00	******	******	68.00	68.0
5	CLINIC CONTROLS	******	******	68.00	67.91	73.12	68.18	70.88	68.00	******	******	68.00	68.0
6	CLINIC CONTROLS	******	******	68.00	67.90	71.36	68.28	69.46	68.00	******	******	68.00	68.0
7	CLINIC CONTROLS	******	******	68.00	67.91	70.72	68.04	69.58	68.00	******	******	68.00	68.0
8	CLINIC CONTROLS	******	******	******	******	87.50	71.83	79.98	69.29	******	******	******	*****
9	CLINIC CONTROLS	68.00	67.70	68.00	67.62	69.99	68.00	69.53	68.00	******	******	******	*****
10	CLINIC CONTROLS	68.00	67.79	68.00	67.73	69.72	68.00	69.32	68.00	68.00	68.00	******	*****

****
*** ZONES ENERGY BUDGET ***
****

CATEGORY CODE = 54000
FACILITY CATEGORY = DENTAL CLINIC
LOCATION = COLUMBIA, MO 1968 TRY
PROJECT TITLE = FT HOOD DENTAL CLINIC

SIMULATION PERIOD = 1 JAN 1968 - 31 DEC 1968
BUDGET REGION = 3
HEATING DEGREE DAYS = 5142.0
COOLING DEGREE DAYS = 1239.5
REQUIRED ENERGY BUDGET= 60

ZONE LOAD

NUMBER	TOTAL HEAT 1000BTU	TOTAL COOL 1000BTU	TOTAL ELECT 1000BTU	TOTAL GAS 1000BTU	INFIL LOSS 1000BTU	INFIL GAIN 1000BTU	TOTAL AREA FT**2	ENERGY BUDGET 1000BTU / FT**2
1000	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	9.384E+03	0.000E+00
1	5.223E+02	5.547E+04	6.972E+04	0.000E+00	0.000E+00	0.000E+00	5.890E+02	2.134E+02
2	1.828E+02	4.223E+04	3.929E+04	2.183E+04	0.000E+00	0.000E+00	2.660E+02	3.892E+02
3	1.699E+04	4.167E+04	4.606E+04	0.000E+00	0.000E+00	0.000E+00	1.330E+03	7.873E+01
4	1.519E+03	1.507E+04	1.729E+04	0.000E+00	0.000E+00	0.000E+00	7.670E+02	4.417E+01
5	1.145E+02	2.530E+04	2.920E+04	0.000E+00	0.000E+00	0.000E+00	6.840E+02	7.986E+01
6	7.355E+02	2.899E+04	1.986E+04	0.000E+00	0.000E+00	0.000E+00	7.710E+02	6.432E+01
7	3.752E+02	3.075E+04	3.396E+04	0.000E+00	0.000E+00	0.000E+00	9.235E+02	7.048E+01
8	0.000E+00	1.209E+05	1.433E+05	0.000E+00	0.000E+00	0.000E+00	9.740E+02	2.713E+02
9	2.470E+04	4.723E+04	5.540E+04	0.000E+00	0.000E+00	0.000E+00	1.242E+03	1.025E+02
10	1.625E+04	3.853E+04	4.287E+04	0.000E+00	0.000E+00	0.000E+00	1.050E+03	9.300E+01
	=========	=========	=========	=========	=========	=========	=========	
TOTAL	6.139E+04	4.462E+05	4.970E+05	2.183E+04	0.000E+00	0.000E+00	1.798E+04	

ENERGY BUDGET FOR ALL ZONES = 5.708E+01 1000BTU / FT**2

*** ZONE ENERGY BUDGETS DO NOT INCLUDE FAN SYSTEMS OR EQUIPMENT INEFFICIENCIES

****
*** SYSTEMS ENERGY BUDGET ***
****

CATEGORY CODE = 54000
FACILITY CATEGORY = DENTAL CLINIC
LOCATION = COLUMBIA, MO 1968 TRY
PROJECT TITLE = FT HOOD DENTAL CLINIC

SIMULATION PERIOD = 1 JAN 1968 - 31 DEC 1968
BUDGET REGION = 3
HEATING DEGREE DAYS = 5142.0
COOLING DEGREE DAYS = 1239.5
REQUIRED ENERGY BUDGET= 60

SYSTEM LOADS

NUMBER	UNDER HEAT 1000BTU	HOURS	UNDER COOL 1000BTU	HOURS	OVER HEAT 1000BTU	HOURS	OVER COOL 1000BTU	HOURS	HEAT W/O DMD 1000BTU	HOURS	COOL W/O DMD 1000BTU	HOURS
1	8.829E+03	(680)	0.000E+00	(0)	0.000E+00	(0)	9.872E+03	(3217)	0.000E+00	(0)	0.000E+00	(0)
	=========		=========		=========		=========		=========		=========	
TOTAL	8.829E+03	(680)	0.000E+00	(0)	0.000E+00	(0)	9.872E+03	(3217)	0.000E+00	(0)	0.000E+00	(0)

NUMBER	TOTAL HEAT 1000BTU	TOTAL COOL 1000BTU	TOTAL ELECT 1000BTU	TOTAL GAS 1000BTU	TOTAL AREA FT**2	ENERGY BUDGET 1000BTU / FT**2
1	6.238E+05	0.000E+00	1.217E+06	2.183E+04	8.597E+03	2.166E+02
	=========	=========	=========	=========	=========	
TOTAL	6.238E+05	0.000E+00	1.217E+06	2.183E+04	8.597E+03	

ENERGY BUDGET FOR ALL SYSTEMS = 2.166E+02 1000BTU / FT**2

*** ENERGY BUDGET DOES NOT INCLUDE UNDER/OVER/W.O. DEMAND HEATING/COOLING ITEMS

****

*** PLANT ENERGY BUDGET ***

****

CATEGORY CODE = 54000
FACILITY CATEGORY = DENTAL CLINIC
LOCATION = COLUMBIA, MO 1968 TRY
PROJECT TITLE = FT HOOD DENTAL CLINIC

SIMULATION PERIOD = 1 JAN 1968 - 31 DEC 1968
BUDGET REGION = 3
HEATING DEGREE DAYS = 5142.0
COOLING DEGREE DAYS = 1239.5
REQUIRED ENERGY BUDGET= 60

PURCHASED ENERGY

PLANT NUMBER	PURCHASED ELECTRIC 1000BTU	BOILER FUEL 1000BTU	GAS TUR-BINE FUEL 1000BTU	DIESEL FUEL 1000BTU	NATURAL GAS 1000BTU	PURCHASED HOT WATER 1000BTU	PURCHASED CHILL WATER 1000BTU
1	1.219E+06	5.723E+05	0.000E+00	0.000E+00	2.183E+04	0.000E+00	0.000E+00
	=========	=========	=========	=========	=========	=========	=========
TOTAL	1.219E+06	5.723E+05	0.000E+00	0.000E+00	2.183E+04	0.000E+00	0.000E+00

PLANT UNMET LOADS / BUDGETS

NUMBER	UNMET HEATING LOAD 1000BTU	UNMET COOLING LOAD 1000BTU	UNMET ELECTRIC LOAD 1000BTU	FLOOR AREA SERVED FT**2	ENERGY BUDGET 1000BTU / FT**2
1	2.108E+05	0.000E+00	0.000E+00	8.597E+03	2.109E+02
	=========	=========	=========	=========	
TOTAL	2.108E+05	0.000E+00	0.000E+00	8.597E+03	

BUILDING ENERGY BUDGET = 2.109E+02 1000BTU / FT**2

*** ENERGY BUDGET DOES NOT INCLUDE UNMET HEATING/COOLING/ELECTRIC LOADS

REQUIRED ENERGY BUDGET = 60 1000BTU / FT**2 FOR DENTAL CLINIC

APPENDIX C:

WEATHER SITES FOR MILITARY BUILDING ANALYSIS

by
Brandt Andersson, Building Systems Analysis Group, Lawrence Berkeley Laboratory (LBL)

For the current energy characterization studies, a set of weather sites representing specific regions was required. This document describes the process for determining those weather sites and regions, and presents the results of that analysis.

Approach

The LBL Building Systems Analysis Group has previously developed a procedure for identifying the most appropriate representative weather sites for specific building energy analysis on a nationwide scale.[14] The method is based on:

- a definition of climate using annual climate parameters representing the key environmental determinants of building energy use: cold--heating degree days (HDD); heat--cooling degree days (CDD); humidity coincident with heat--latent enthalpy hours (LEH); and sunshine (KT).

- a desire to weight the importance of a particular climate by the population represented (by use of the 125 largest Standard Metropolitan Statistical Areas [SMSAs]), and

- a quantitative definition of climatic similarity.

The procedure is intended to create climate regions that can be reasonably represented by a single weather site and that contain a significant portion of the target population. Thus, in organizing a set of population centers there are two often conflicting goals: to split on the sets with the largest populations and to split on the sets which vary most from other climates. This conflict is resolved through iteration and statistical analysis of the resulting groups.

Military Population

The military population is distributed in a considerably different manner than the population at large. Thus, the set or population centers (SMSAs) had to be altered to correct this difference. Rather than develop an entirely new data base, it was decided to modify the populations in the existing data base to reflect the military population

[14] B. Andersson, W. Carroll, and M. Martin, *Aggregation of U.S. Population Centers Using Climate Parameters Related to Building Energy Use*, Report LBL-1523 (Lawrence Berkeley Laboratory, 1985); also in *ASHRAE Transactions*, Vol 91, 2B (1985), pp 183-205; also in *Journal of Climate and Applied Meteorology*, Vol 25, No. 5 (1986), pp 596-614.

distribution. The ratio of military personnel[15] to population in each state was used to adjust the population of each metropolitan area in that state.

The result was an approximate number of military personnel represented by each SMSA. Two sets of representative weather sites were developed using this data base. Upon consideration of the result, two concerns were expressed regarding the data base. One was the question of military population distribution within states, which was not accounted for in the data base. The second was the inclusion of all military personnel, although this study will be focussed on the Army and Air Force. To respond to these concerns, an entirely new data base was developed from materials provided by USACERL.[16]

The result was a set of 158 Army and Air Force installations, with associated climate parameters and populations, representing a total of slightly more than 2,000,000 people. A list of the bases is included with this report (Table C1). Figure C1 shows, by use of the open circles, the relative military population in different areas. It can be seen that Washington (DC), Texas, and the Carolinas are the most important centers, with secondary centers in the deep South, Kentucky, Oklahoma, Colorado, the Southwest, and Washington (State). The traditionally dominant population centers of the Northeast and Midwest are reduced to a trivial role.

Weather Site Sets

Two lists of weather sites have been drawn up (Table C1). For the initial energy characterization, a list of 3 to 5 sites was desired, simply to illustrate the range of variation due to broad climatic differences. For analyses that appear particularly sensitive to climatic variation, and for the effects of climate dependent conservation techniques, a list of 8 to 10 sites was contemplated to minimize the climatic variation within the region represented by each weather site.

Results

Application of the iterative process resulted in two sets or weather sites, a set of five and a set of ten. They balance the issues of represented population, climatic variation within the set of population centers being represented by a single weather site, and geographic contiguity. For consistency, the five sites on the short list are also part of the larger set. Each of the 158 bases is "associated" with one of the weather sites in each set. Association with a weather site indicates that the climate of the SMSA is closer to that of the associated weather site than any of the other weather sites in the set. Similarity is gauged by a metric of similarity for each of the four annual climatic parameters. Table C1 gives a tabular description of the geographic regions and military population represented by the weather sites in each of the two sets.

Figure C1 gives a geographic view of the chosen weather sites and the regions they represent. It is important to explain the relationship between the weather sites for which analysis will be done and the other population centers that fall in the same climate group. The population centers are divided into groups by identifying a set of key weather

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[15] *Statistical Abstract of the United States* (1982), p 347.
[16] *Guide to Military Installations*.

Table C1

Weather Sites, Population, and Important Associated Bases

Weather Site	Represented Military	Important Bases in the Group Associated with the Weather Site
		Short List - Five Weather Sites
Atlanta	477,000	Ft. Benning, Ft. Bragg, Ft. Campbell, Ft. Sill
San Antonio	445,000	Ft. Hood, Ft. Sam Houston, Eglin AFB, Ft. Polk
Washington	381,000	Ft. Riley, Offutt AFB, Ft. Knox, Ft. Leonard Wood
Colorado Sp.	378,000	Ft. Lewis, Ft. Carson, Ft. Ord, Elmendorf AFB
El Paso	316,000	Ft. Bliss, Nellis AFB, Luke AFB, Travis AFB
		Long List - Ten Weather Sites
Mobile	271,000	Ft. Benning, Eglin AFB, Ft. Polk, Keesler AFB
San Antonio	250,000	Ft. Hood, Ft. Sam Houston, Schofield Barracks, MacDill AFB
Washington	249,000	Offutt AFB, Ft. Knox, Ft. Meade, Aberdeen Pr. Gr.
El Paso	234,000	Ft. Bliss, Nellis AFB, Luke AFB, Davis-Monthan AFB
Colorado Sp.	232,000	Ft. Carson, Hill AFB, Elmendorf AFB, Lowry AFB
Atlanta	197,000	Ft. Sill, Ft. Jackson, Little Rock AFB, Shaw AFB
Raleigh	193,000	Ft. Bragg, Ft. Campbell, Langley AFB, Johnson AFB
Olympia	138,000	Ft. Lewis, Ft. Devens, McChord AFB, Griffiss AFB
Sacramento	134,000	Ft. Ord, Travis AFB, Castle AFB, Kirtland AFB
St.Louis	99,000	Ft. Riley, Ft. L-Wood, Scott AFB, McConnell AFB

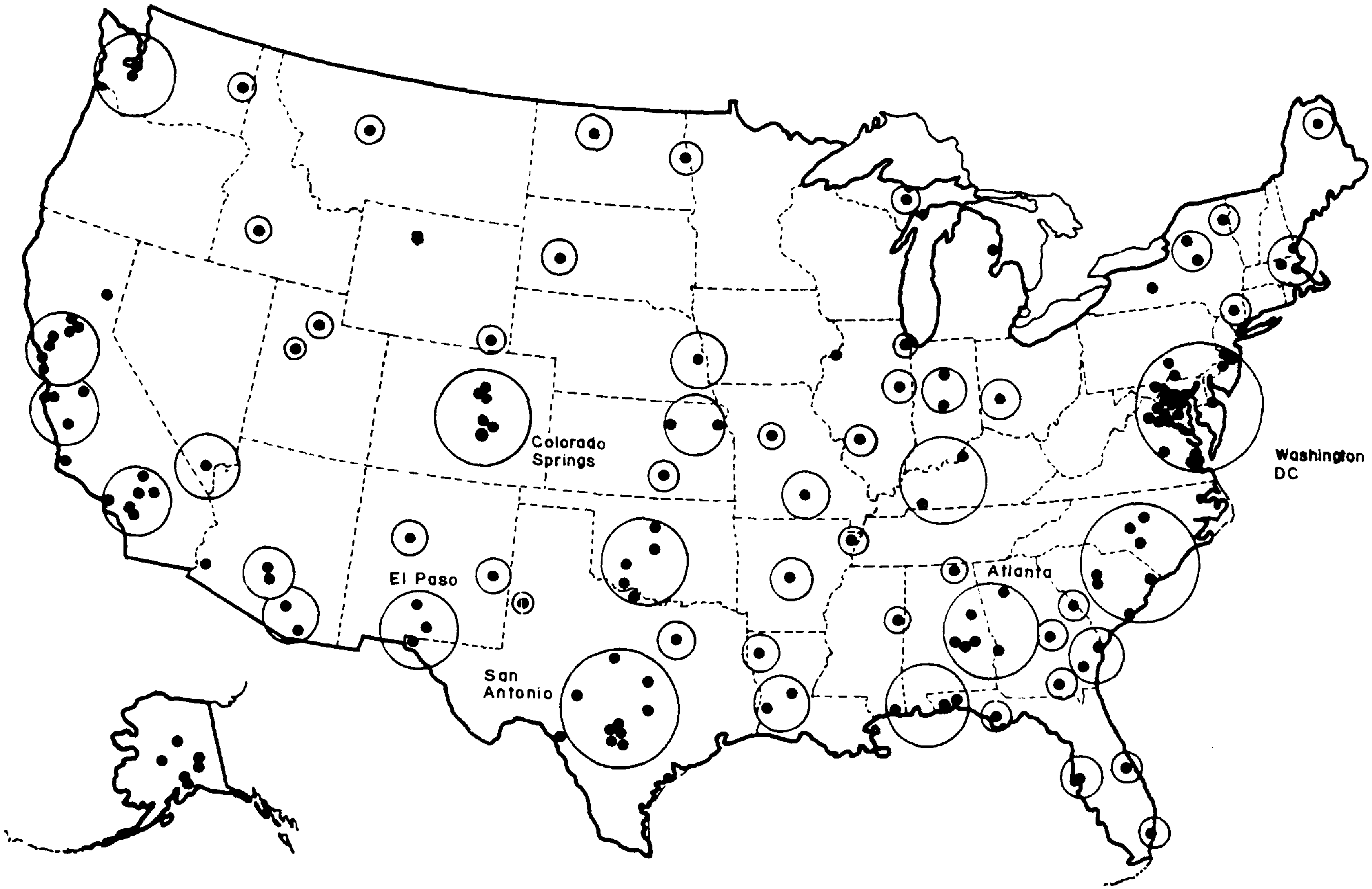

Figure C1. Relative military population in the United States.

sites (like those above) that effectively span the range of climates being evaluated. Some of the considerations that go into choosing those weather sites are:

1. Assuring that a maximum of the bases under consideration are similar to one of the weather sites

2. Determining that each of the weather sites is close to the average weather parameters of all the population centers in that group, weighted by their respectively military populations

3. Achieving geographic contiguity to the extent possible, consistent with the first two goals.

Once the weather sites and their associated population centers have been chosen, building analysis is done only for the weather site. Other locations can reference the analysis done for the weather site with which they are associated.

It is highly preferable to avoid choosing a low-population weather site for analysis, even though it might prove very interesting. If the results are applicable to few population centers, the usefulness of the result is not sufficient, on a national scale, to justify such scrutiny. It is for that reason, for example, that no site in Alaska has been chosen for analysis; interesting though it may be, no site in Alaska would be representative outside the state or even to much of the rest of Alaska. The resident military population is insufficient for special study.

Table C2 gives a synopsis of the weather parameters of each of the chosen weather sites, together with population-weighted mean values of the same weather parameters for all the population centers represented.

It is useful to understand the value of each parameter for both the weather sites and their represented groups, relative to the full range across the country. Table C3 orders the values of each climate parameter for each weather site and each group.

It can be seen that, given the range of values of each parameter, the weather sites to be used for the analysis typically represent each parameter of the full group quite well. The one notable exception may be the level of sunshine in Colorado Springs in the long list. The Associated Group as a whole is noticeably cloudier (.577 vs .621 K_T) and colder (7348 vs 6374 HDD). This is because the association of colder and cloudier climates along the northern border and in Alaska lowers the overall K_T and raises the HDD of the group. When applying results from Colorado Springs to these climates, one should consider this factor. Also in the long list, Atlanta is cloudier than the group as a whole (.495 vs .530 K_T) because of the importance of the Oklahoma and Texas climates to that group. Note should be taken of that distinction when applying the Atlanta results to those bases. Generally, however, the fit of climates is particularly good because of the concentration of military population.

Table C2

Climate Parameters for Weather Sites and Associated Groups

Weather Site/ Associated Group*	Represented Military Population	Climate Parameters: Population-Weighted Means and Specific Weather Sites			
		HDD	CDD	LEH	K_T
		Short List - Five Weather Sites			
Atlanta	477,000	3149	1836	23382	.510
Atlanta	4,100	3094	1588	23500	.495
San Antonio	445,000	1429	2949	35754	.516
San Antonio	76,500	1570	2993	35900	.531
Washington	381,000	5337	1054	15088	.485
Washington	45,200	5008	940	16200	.472
Colorado Springs	378,000	6513	335	2472	.545
Colorado Springs	72,200	6374	461	1400	.621
El Paso	316,000	2537	2276	4492	.676
El Paso	63,300	2677	2097	5400	.687
		Long List - Ten Weather Sites			
Mobile	271,000	1892	2439	34676	.499
Mobile	70,300	1683	2576	36500	.495
San Antonio	250,000	1182	3286	34700	.531
San Antonio	76,500	1570	2993	35900	.531
Washington	249,000	5235	1039	14276	.478
Washington	45,200	5008	940	16200	.472
El Paso	234,000	2361	2625	5158	.686
El Paso	63,300	2677	2097	5400	.687
Colorado Springs	232,000	7348	463	2396	.577
Colorado Springs	72,200	6374	461	1400	.621
Atlanta	197,000	3028	2089	22836	.530
Atlanta	4,100	3094	1588	23500	.495
Raleigh	193,000	3527	1432	22100	.488
Raleigh	80,100	3514	1393	21800	.488
Olympia	138,000	6421	264	5106	.436
Olympia	68,200	5530	101	2700	.436
Sacramento	134,000	3036	833	2014	.628
Sacramento	47,700	2842	1157	2100	.638
St. Louis	99,000	4978	1400	20852	.534
St. Louis	12,600	4748	1474	19900	.517

*Bold type = Associated Group, regular type = Weather Site.

Table C3

Weather Sites and Associated Groups Ranked by Individual Climate Parameter

HDD		CDD		LEH		K_T	
				Short List - Five Weather Sites			
Colorado Sp.*	6513	San Antonio	2993	San Antonio	35900	El Paso	.687
Colorado Sp.	6374	**San Antonio**	2949	**San Antonio**	35754	**El Paso**	.676
Washington	5337	**El Paso**	2276	Atlanta	23500	Colorado Sp.	.621
Washington	5008	El Paso	2097	**Atlanta**	23382	**Colorado Sp.**	.545
Atlanta	3149	**Atlanta**	1836	Washington	16200	San Antonio	.531
Atlanta	3094	Atlanta	1588	**Washington**	15088	**San Antonio**	.516
El Paso	2677	**Washington**	1054	El Paso	5400	**Atlanta**	.510
El Paso	2537	Washington	940	**El Paso**	4492	Atlanta	.495
San Antonio	1570	Colorado Sp.	461	**Colorado Sp.**	2472	**Washington**	.485
San Antonio	1429	**Colorado Sp.**	335	Colorado Sp.	1400	Washington	.472
				Long List - Ten weather Sites			
Colorado Sp.	7348	**San Antonio**	3286	Mobile	36500	El Paso	.687
Olympia	6421	San Antonio	2993	San Antonio	35900	**El Paso**	.686
Colorado Sp.	6374	**El Paso**	2625	**San Antonio**	34700	Sacramento	.638
Olympia	5530	Mobile	2576	**Mobile**	34676	**Sacramento**	.628
Washington	5235	**Mobile**	2439	Atlanta	23500	Colorado Sp.	.621
Washington	5008	El Paso	2097	**Atlanta**	22836	**Colorado Sp.**	.577
St. Louis	4978	**Atlanta**	2089	**Raleigh**	22100	**St. Louis**	.534
St. Louis	4748	Atlanta	1588	Raleigh	21800	San Antonio	.531
Raleigh	3527	St. Louis	1474	**St. Louis**	20852	**San Antonio**	.531
Raleigh	3514	**Raleigh**	1432	St. Louis	19900	**Atlanta**	.530
Atlanta	3094	**St. Louis**	1400	Washington	16200	St. Louis	.517
Sacramento	3036	Raleigh	1393	**Washington**	14276	**Mobile**	.499
Atlanta	3028	Sacramento	1157	El Paso	5400	Atlanta	.495
Sacramento	2842	**Washington**	1039	**El Paso**	5158	Mobile	.495
El Paso	2677	Washington	940	**Olympia**	5106	**Raleigh**	.488
El Paso	2361	**Sacramento**	833	Olympia	2700	Raleigh	.488
Mobile	1892	**Colorado Sp.**	463	**Colorado Sp.**	2326	**Washington**	.478
Mobile	1683	Colorado Sp.	461	Sacramento	2100	Washington	.472
San Antonio	1570	**Olympia**	264	**Sacramento**	2014	**Olympia**	.436
San Antonio	1182	Olympia	101	Colorado Sp.	1400	Olympia	.436

*Bold type = Associated Group, regular type = Weather Site.

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